DOCUMENT RESUME

ED 278 551 SE 047 715

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|---|---|
| AUTHOR | Gallagher, James J. |
| TITLE | A Summary of Research in Science Education--1985. |
| INSTITUTION | ERIC Clearinghouse for Science, Mathematics, and Environmental Education, Columbus, Ohio.; National Association for Research in Science Teaching. |
| SPONS AGENCY | Office of Educational Research and Improvement (ED), Washington, DC. |
| PUB DATE | Dec 86 |
| CONTRACT | 400-86-0016 |
| NOTE | 193p.; This document will be published in the journal "Science Education." |
| AVAILABLE FROM | John Wiley and Sons, Inc., 605 Third Ave., New York, NY 10016 (Contact publisher for price). |
| PUB TYPE | Reports - Descriptive (141) -- Information Analyses - ERIC Information Analysis Products (071) |
| EDRS PRICE | MF01/PC08 Plus Postage. |
| DESCRIPTORS | *Academic Achievement; Cognitive Development; Computer Assisted Instruction; Concept Formation; Educational Research; Elementary Secondary Education; Higher Education; Literature Reviews; Misconceptions; *Science Curriculum; *Science Education; Science Instruction; Science Teachers; Student Attitudes; Student Characteristics; *Teacher Education; *Teaching Methods |
| IDENTIFIERS | *Science Education Research |

ABSTRACT

This review of research in science education consists of 432 reports published in 1985. Data sources include science education journals that regularly appear in the "Current Index to Journals in Education," reports entered into the ERIC system in "Resources in Education," and dissertations reported in "Dissertation Abstracts." Summaries are provided for most of the citations. These summary statements are in 12 categories which include: (1) reviews of research; (2) evaluation (including broad scale assessment and test development and analysis); (3) student characteristics and educational outcomes (highlighting predictors and correlates of achievement); (4) attitudes toward science; (5) student concepts and conceptual reasoning (studies on misconceptions, conceptual change, and the New Zealand Learning in Science Project); (6) instructional treatment and student achievement (reporting findings identified at different grade levels, with gifted students, and in non-formal settings); (7) influence of instruction on cognitive skills; (8) laboratory work; (9) microcomputer applications; (10) curriculum (studies in content analysis, curriculum development and implementation); (11) practice in science teaching (including exemplary practices); and (12) teacher preparation (both preservice and inservice studies as well as teacher attributes and supply). A bibliography of studies reviewed concludes the document. (ML)

ED278551

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# SCIENCE EDUCATION INFORMATION REPORT

A SUMMARY OF RESEARCH IN SCIENCE
EDUCATION -- 1985

THE ERIC SCIENCE, MATHEMATICS AND
ENVIRONMENTAL EDUCATION CLEARINGHOUSE
in cooperation with
Center for Science and Mathematics Education
The Ohio State University

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by

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# A SUMMARY OF RESEARCH IN SCIENCE EDUCATION -- 1985

Published by:

ERIC® Clearinghouse for Science,
Mathematics, and Environmental Education
The Ohio State University
1200 Chambers Road, Room 310
Columbus, Ohio 43212

December, 1986

OERI
Office of Educational Research and Improvement
U.S. Department of Education

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# Preface

The Summary of Research in Science Education series has been produced to analyze and synthesize research related to the teaching and learning of science completed during a one-year period of time. These summaries are developed in cooperation with the National Association for Research in Science Teaching. Individuals identified by the NARST Research Committee work with staff of the ERIC Clearinghouse for Science, Mathematics, and Environmental Education to review, evaluate, analyze, and report research results. The purpose of the summaries is to provide research information for practitioners and development personnel, ideas for future research, as well as an indication of trends in science education research.

Readers' comments and suggestions for the series are invited.

Stanley L. Helgeson
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# A Summary of Research in Science Education — 1985

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## Introduction

This year's annual review of science education research was compiled from the bibliographic data provided to the writer by the SMEAC Information Reference Center, 1200 Chambers Road, Columbus, OH 43212. They provided a listing of over 400 citations accompanied by abstracts of articles, reports, and dissertations. The data sources used by SMEAC included the science education journals which they regularly abstract for inclusion in Current Index to Journals in Education, reports entered into the ERIC system that are a part of the publication Resources in Education, and dissertations that are reported in Dissertation Abstracts.

The summary of research which follows is only that--a summary of research. It is only slightly interpretative. It definitely is not a critical review of research. The task is too broad in scope to allow for more than limited interpetation. Critical reviews, on the other hand, require a far narrower scope and by their nature, they must cut across many years of research. Critical reviews of science education research are needed and this writer has indicated several areas where our profession would benefit from them. However, this is a summary of research published during 1985 and in its broad scope, yet inherently limited depth, it serves an important function in our field.

The abstracts provided by SMEAC were used as a starting point for preparation of this report. For many citations, abstracts provided insufficient information upon which to prepare a concise description of the research and its findings. Thus, it was necessary to refer to journal articles and other published reports to prepare text for this summary. While this was relatively easy with journal articles, it was far more time consuming and costly with dissertations. Thus, most reports on dissertations are based on abstracts prepared by authors for Dissertation Abstracts.

Using data provided by SMEAC, supplemented by analyses of most of the included journal articles, summary paragraphs were written for each of the citations. These summary paragraphs were categorized into an emergent category system, devised from the studies published in 1985. Attempts were made to utilize seven category systems found in previous reviews. However, these proved unsatisfactory in two counts. First, they did not conform adequately to the 400 plus reports included in the 1985 research array. Second, they did not "work" for the author. Thus, the outline shown below constitutes the category system used in this 1985 Review:

I. Reviews of Research

II. Evaluating Science Education
    A. Broad Scale Assessments
    B. Test Development and Analysis

III. Student Characteristics and Educational Outcomes
    A. Predictors of Achievement
    B. Cognitive Developmental Correlates of Achievement
    C. Affective Correlates of Achievement
    D. Factors Affecting Choice of Major and Career

IV. Attitudes Toward Science

V. Students Concepts and Conceptual Reasoning
    A. Student Characteristics and Concept Attainment
    B. Students' Conceptual Reasoning
    C. Students' Concepts and Misconceptions
    D. Conceptual Change Teaching
    E. The New Zealand Learning in Science Project

VI. Instructional Treatments and Student Achievement
    A. General Studies
    B. Tertiary Level Studies
    C. Secondary Level Studies

D. Elementary Level Studies
E. Science Instruction for Gifted Students
F. Non-formal Education in Science

VII. Influence of Instruction on Cognitive Skills
  A. Influences of Academic Instruction
  B. Direct Intervention upon Cognitive Skills
  C. Spatial Visualization

VIII. Research on Laboratory Work in Science Instruction

IX. Microcomputer Applications in Science Instruction

X. Curriculum
  A. Analysis Curricular Content
  B. Curricular Objectives
  C. Teachers' Selection of Content
  D. Program Comparisons
  E. Curriculum Development
  F. Curriculum Implementation
  G. Textbooks

XI. The Practice of Science Teaching
  A. Descriptions of Practice
  B. Studies of Exemplary Practices
  C. Perceptions of the Workplace of Science Teaching
  D. Classroom Environment and Teacher Effectiveness Research
  E. Studies of Homework and Examinations
  F. Enrollment Patterns in Science

XII. Studies of Teacher Preparation
  A. Teacher Supply
  B. Research on Teacher Attributes
  C. Preservice Teacher Education
  D. Inservice Teacher Education

With this organizational structure and summary paragraphs in place, assembly of the report moved quickly. For each section, an introduction was written, summary paragraphs were placed in a sequence and interpretive commentary was added. Sequencing of summary paragraphs was based generally on level of schooling: tertiary, secondary, elementary. Similar topical areas were clustered within this larger order.

Preparation of interpretive commentary as well as the organizational scheme for this report are idiosyncratic. I hope both are helpful to readers and provocative of debate, dialogue and actions.

## Reviews of Research

Fourteen reviews or compendia of science education research were reported during 1985. These are listed with brief annotations.

Hurd (185) prepared an update on science education research in an effort to bridge the gap between educational research and science teaching practices. The database for this research was derived from educational issues that have their origin in social processes and from those generated by public pressure, such as the back to basics movement and the evolution/creation controversy. A summary of recommendations found in national studies which use naturalistic research techniques shows several patterns of agreement on new directions for science education. For example, the overall purpose of education in the sciences is to develop culturally literate and responsible citizens for participating in a modern science/technology oriented democracy. In addition, the core curriculum should be a balance of science and technology presented as an integrated system and should include both biological and physical science concepts.

Welch (415) provided a retrospective critique of science education research during the past decade. He defined the domain of science education and offered a synthesis of recent research, drawing on meta-analysis of research, and other comprehensive works, on student characteristics and outcomes, student traits and outcomes, teacher characteristics and student outcomes, teacher behaviors, and instructional systems. He concluded this analysis with recommendations for research questions that offer promise for improving teaching and learning of science.

McCurdy (249) reported conclusions from Project Synthesis which bear on tertiary programs including the need for high motivation materials for non-science majors, government support for inservice training, and certification revisions.

Lawson (226)' conducted a review of research in developmental psychology and science education which has attempted to assess the validity of Piaget's Theory of Formal Thought and its relation to educational practice. This review addresses six questions: (1) What is the role of biological maturation in the development of formal reasoning? (2) Are Piaget's tasks reliable and valid? (3) Does formal reasoning constitute a unified general mode of intellectual functioning? (4) How does the presence or absence of formal reasoning affect school achievement? (5) Can formal reasoning be taught? (6) What is the structural or functional nature of advanced reasoning? Lawson's general conclusion is that although Piaget's work and subsequent research leaves some unresolved theoretical and methodological questions, it provides important background from which substantial progress can be made toward the significant educational objective of improving students' reasoning abilities.

Gilbert and Swift (146) described Lakatos' analysis of a scientific research program and applied it to Piagetian and alternative conceptions research. Similarities and differences between these two research paradigms are presented along with fundamental assumptions, auxiliary hypotheses, and research policies. The authors conclude that individuals' alternative conceptions have been subordinated to their ascribed Piagetian stage of intellectual development in much of the research literature; the alternative conceptions movement represents a return to an earlier age of theoretical innocence similar to Piaget's work of the 1920's. They also caution against translation of reseach findings from one program to the other.

Berty and Esquivel (28) reported on trends in science education research in Costa Rica during the 12 year period from 1973 to 1985. The majority of studies completed during that period were diagnostic in nature. General findings were listed under the headings of certification, supervision, basic skills, teaching methods, attitudes, and curriculum. The diagnostic stage is now considered over, and a new phase is beginning which will emphasize initiation and evaluation of teaching innovations and improved teacher education programs.

The 1983 Annual Review of Science Education research was reported by Holiday et al., (177) and Holiday and McGuire (178). Abstracts of the papers presented at the 58th Annual Meeting of the National Association for Research in Science Teaching were edited by Blosser and Helgeson (45).

Bethel (29) edited a monograph containing 17 research studies in science education conveying a wide array of topics.

Tisher (391) edited a report of the 15th Annual Conference of the Australian Educational Research Association meeting. This report includes information on investigations of students' science concepts and alternate frameworks used to interpret natural phenomena including: (1) high school chemistry students' concepts about stoichiometry and amino acids, (2) high school students' pre-instructional concepts about mechanics and circular motion,

(3) children's ideas about floating and sinking, and (4) children's interpretations of the word "solid." The report is a rich compendium of research findings on a variety of topics. Researchers will find the report a useful resource.

A listing of theses and dissertations submitted for higher degrees at British Universities was published in the Studies in Science Education and two short compendia of reports of research were published in School Science Review. Both journals are published in the United Kingdom.

Studies in Science Education provides a listing of these reports and dissertations for degrees in British Universities completed during 1982-83, including some not previously listed. They are arranged under 18 headings reflecting studies of teaching/learning in biology, chemistry, physics, technology, elementary and secondary school mathematics, schools and industry, computers, attitudes, concept formation, and science/mathematics education overseas.

A report in School Science Review provided information on an inservice course in primary science, improving physics teaching, reducing chemistry curriculum, textbook readability measures, school-industry link for introductory engineering, local education authority initiatives in primary school science, and "Winnie the Pooh" as science for children.

Our profession can benefit greatly from the kind of serious scholarship which is represented by works such as those by Hurd, Welch, Lawson, Gilbert and Swift, and Berty and Esquival. Science education has been deficient in critical analysis of research such as is represented in these reports. More work of this type is needed. Dissertation writers and their professors should give more attention to thorough critical analysis of literature pertinent to specific topics as a key part of dissertation research. Further, dissertation writers should be encouraged to publish comprehensive critical reviews of specific topics as an important addition to the science education literature.

## Evaluating Science Education

Studies grouped in this broad category pertain to broad-scale assessments of the effectiveness of science education and test development activities.

### Broad Scale Assessments

Eight studies were reported which focused on the National Assessment of Educational Progress, the Second International Science Study, a curriculum-tracking study, and a national appraisal of science education in Canada.

Fraser et al. (135) used a model of educational productivity, involving nine aptitude, instructional, and environmental variables, to conduct a secondary analysis of data on 1,960 nine-year old students from 124 U.S. elementary schools as part of the National Assessment of Educational Progress. When controlled for other factors, ability, motivation, class environment, home environment, television viewing (negative direction), gender, and race were all found to be related significantly to achievement. Factors related to positive attitudes were ability, motivation, classroom environment, and race. Findings supported the model of educational productivity and suggested that students' achievement and attitudes are influenced collectively by multiple factors rather than by one or two dominant ones. The study also attests to the potential value of secondary analysis of databases from National Assessments.

Aikenhead, Ryan, and Flemming (3) reported on a study of 10,000 Canadian high school students nearing graduation as part of the Canadian IEA Study. Students were presented with several statements on science-related societal issues and asked to give their opinion regarding agreement, disagreement or uncertainty and to write a paragraph explaining reasons for their choice. Results showed that the meanings ascribed to these statements by students often are very different from those meanings which teachers and researchers ascribe to them. More specific findings are reported which focus on three topics: (1) interactions among science, technology, (2) characteristics and limitations of scientific knowledge, and (3) characteristics of scientists.

Jacobson and Doran (190) compared the performance of ninth-grade students on 30 common test items given during the First (1970) and Second (1983) International Science Studies, including differences related to gender. Findings, among others, show that overall, students in 1983 scored higher than did their predecessors in 1970.

Yager and Yager (426) studied perceptions of science among third, seventh, and eleventh graders using data from the 1977 and 1982 Reports of the National Assessment of Educational Progress and two studies conducted in Iowa. Results showed that: (1) science is perceived as less fun and exciting by older students, (2) teachers are perceived as information providers by all students, (3) older students have less curiosity and feel less successful than do younger ones, and (4) students do not perceive that school programs encourage entry into science careers.

Vanfossen et al. (399) conducted a study of the effects of curriculum tracking of 3,932 high school students over a two-year period using multiple regression analysis. Results show that curriculum placement is related to courses taken and consequently to cognitive performance in science and math, which is independent of the effects of prior ability, educational expectations, and social class. Curriculum tracking is also related to change in levels of educational and occupational aspirations, satisfaction with school, friendship patterns and classroom experiences. This study reinforces the view that schools can accentuate small individual differences both positively and negatively.

Connelly et al. (90) reported a two-year study of policies, practices, and perceptions of science education in Canada as part of a 25-nation study. A history of Canadian science education is presented along with analysis of current programs and practices by provinces.

Orpwood and Souque (284) reported on a four-year national study of science education in Canada. The report, which summarizes a longer report prepared by the Science Council of Canada, has three components: (1) Issue Identification: What are the problems? (2) Data Collection: What are the facts? (3) Option Development: 'Where do we go from here? Eight major conclusions are reported which include the need for guaranteeing science education in every elementary school, greater opportunities for girls, challenging high achievers, emphasizing science-technology-society connections, and ensuring quality through assessments and monitoring.

Orpwood (283) described the "deliberative inquiry model," a strategy developed for investigating science education in Canada.

Assumptions of the model are addressed, with information on position papers, curriculum policies, textbook analysis, teacher surveys, and case studies provided. The report indicates that the project created momentum for deliberation which is continuing.

These eight studies provide important data about the effects and effectiveness of science teaching in the U.S. and Canada. While the findings by Jacobson and Doran appeared to offer some "good news" regarding achievement gains for U.S. students between the 1970 and 1983 International Assessments, Yager and Yager's analysis of National Assessment data provided "bad news" in that older students' interests and attitudes in science were less positive than those of younger students. Adding these results to the secondary analysis done by Fraser et al., which showed that achievement and attitudes were influenced as shown in Table 1, a fuller picture occurs. These results are not entirely clear, however.

Table 1. Summary of Findings By Fraser, et al.

| Factor | Achievement | Attitudes |
|---|---|---|
| Ability | + | + |
| Motivation | + | + |
| Class Environment | + | + |
| Home Environment | + | |
| TV Viewing | − | |
| Gender (Male) | + | |
| Race (White) | + | + |

Fraser et al. showed that achievement and attitudes are influenced positively by classroom environment. Yager and Yager showed that older students who presumably have more experience in science classrooms have less positive attitudes. These findings engender several questions including, "What underlies the decline in attitudes?" and "How does this influence achievement, career choice, etc?" Studies of the type conducted by Vanfossen et al., along with further analysis of extant data from National Assessment, have potential for improving our understanding of the effects and effectiveness of science instruction.

The national study of science education in Canada was a comprehensive project which was well supported and staffed. It is an important work with significant applications for Canada. Science educators from other nations, including the U.S., should review this work carefully to assess its applicability to other national contexts.

## Test Development and Analysis

Thirteen studies are reported in this section which examine the development of analysis of science-related tests. The range is from college to first grade. Tests of achievement, attitudes, and reasoning skills are included. In addition, one article examines the influence of testing on curriculum.

Hartshorn (158) reported on the development of a paper-pencil Piagetian reasoning instrument for community college math and science students. Two preliminary forms of the Assessment of Piagetian Reasoning Levels (APRL) were tested on 605 math and science students from four colleges of the Virginia Community College System. A final field test of the APRL utilized 927 subjects from these same four colleges. The data collected from the preliminary studies were subjected to extensive item analysis. Forty-seven subjects were also clinically assessed and their performances compared on both forms of assessment. These results, along with the item analysis data, led to the choice of 19 items for inclusion in the final version of the APRL. On the basis of extensive statistical analyses, the APRL was shown to have high reliability, substantial concurrent validity, and the type of factor validity predicted by Piagetian theory. It demonstrated the capability of classifying subjects into concrete-operational, transitional, and formal-operational levels in much the same way that they were independently categorized by a Piagetian interview.

Marsh and Anderson (247) developed a 46-item multiple choice Biomathematics Skills Choice Test to assess 23 mathematical competencies needed in introductory college biology. When administered to students in introductory biology courses, Biomathematics Skills Test scores and high school grade point average were predictors of success for both declared majors in biology and students majoring in other fields.

Clive (84) conducted a trial test of the items and instruments used in the Second IEA Science Study and used trial test data to test the validity of the assumed hierarchical nature of the cognitive domain of the Taxonomy of Educational Objectives. This test of validity was limited to levels 1-3: knowledge, comprehension, and application. The two major hypotheses examined using trial testing scores were: (1) mean item difficulties increase as level of taxonomic category increases and (2) a simplex pattern is displayed by intercorrelations between taxonomic categories. Both hypotheses were rejected on the basis of the analysis revealing that the evidence was inconclusive as to the validity of the hierarchical nature of the cognitive objectives in Bloom's Taxonomy. The recommendation was made that further data analysis, keeping knowledge category scores constant, and including other variables (such as opportunity to learn data) in the analysis, would provide more conclusive results. However, it was admitted that in spite of the controversy over the hierarchical nature of the categories, Bloom's Taxonomy proves a useful tool in education.

Esquivel and Quesada (118) reported on the development, validation, and administration of a criterion-referenced science battery for general education students in Costa Rica. Following test development, students in grades four, six, seven, and ten from 127 public elementary and 43 public secondary schools were tested. It was found that: (1) the tests have a high internal consistency, (2) student achievement in science was very low, and (3) regional variations were found which corresponded to documented deficiencies in science instructional materials and preparation of teachers.

Weerasooriya (413) developed an instrument to assess students' opinions regarding the validity of the objectives of the American Chemical Society's Chemistry in the Community Project and to assess the extent to which these objectives are perceived as being met. The investigator developed a questionnaire using simplified statements of the project's objectives. Using the PROVUS Discrepancy Model, it was learned that developers, teachers, and students demonstrated a high level of agreement regarding the appropriateness of the objectives of Chemistry in the Community. Further, data show that the objectives have been met to a great extent.

The discrepancy between expected and actual outcomes of inquiry approaches to science teaching suggests that there is an urgent need for systematic evaluation of the approach. Hur (184) conducted a study to develop a comprehensive instrument for evaluating inquiry teaching approaches embedded in science curricular materials. The first part of the instrument consists of science processes grouped into four sections: (1) gathering and organizing data, (2) interpreting and analyzing data, (3) synthesizing results and evaluation, and (4) hypothesizing and designing an experiment. The second part of the instrument contains four evaluation scales of inquiry activity: (1) competition/cooperation scale, (2) discussion scale, (3) openness scale, and (4) inquiry scope scale. The last part consists of three methods for evaluating a science laboratory curriculum as a whole: (1) inquiry pyramid, (2) inquiry index, and (3) difficulty index. The instrument is designed to be used by teachers, science curriculum developers, and science education evaluators for the purpose of diagnosing the nature and appropriateness of scientific inquiry introduced in secondary science curricular materials, especially in laboratory work and field work.

Donovan, Fronk, and Horton (110) described the development and validation of a 56-item science and engineering career interest survey for seventh through ninth-grade students. The survey includes questions on occupational activities, selection of occupations, and an internal verification scale. Results indicate significant differences in career interest for boys and girls.

Rojanapanut (321) developed and validated a mastery test of science achievement for use with first-grade students in Thailand. The completed test contains 60 items. Validity and reliability data are provided.

Padilla et al. (291) reported on the development and validation of a Test of Basic Process Skills in Science, designed for use with students in grades four through eight. The 36-item, multiple-choice test measures students' competence in six basic processes: observation, inference, prediction, measurement, communication, and classification. Two versions were produced and validated. Results showed appropriate reliability, item difficulty, and discrimination indicies.

Burns, Okey, and Wise (63) developed a 36-item test of integrated process skills for use with middle and high school students which can be completed by students in a normal class period. Data on reliability of TIPS II are provided and comparisons are made with an earlier test, TIPS.

Calhoun (68) developed and validated a Likert-type scale to test the attitudes of select subjects toward the generation of electricity from nuclear power plants. A 15-step flowchart model was applied to the construction of a 20-item long form and a 6-item short form of the scale. Both scales were field-tested on 829 respondents representing a diverse range of subjects; high school juniors and seniors, nuclear engineering students, preservice teachers and members of a citizens action group. Both scales are available for immediate use and both scales appear to meet criteria regarding validity and reliability.

Stefanich et al. (360) assessed the concurrent validity of Ankeny and Joyce's Piagetian Reasoning Test among 50 students in grades four. Students were classified as concrete operational if they demonstrated mastery on 8 or more operations contained in this paper-pencil test. Subsequently, students were interviewed using Piagetian tasks which paralleled the 10 operations of the Reasoning Test. Results show that a significantly larger portion of students demonstrated concrete operational thought process on task interviews as compared to printed (and oral) questions reflecting the same operations.

Tamir (381) described changes and effects of the Israeli paper-and-pencil matriculation examination in biology since its first analysis in 1972. The examination has been significant for implementing an inquiry-oriented high school biology program based on the Biological Sciences Curriculum Study. The author concludes that the production of high quality, valid, reliable, and interesting tests is not easy and requires serious investment of time, expertise, and talent. However, the impact of such high quality examinations on teaching practice and, subsequently, on student learning is so great that efforts and investments are justified.

A rule of thumb of test developers is that development of a test requires at least one person working for one year. Without implying criticism of test development efforts reported here, science educators need to recognize that test development is important, difficult, and expensive work which should not be entered into casually. A large number of reliable, valid instruments have been prepared in past years. Researchers may benefit from concentrating efforts on use of existing instruments rather than expending effort and other resources on developing new instruments.

Of course, there must be a caveat in the foregoing admonition: New questions may require new instruments.

Finally, Tamir's point must be underscored. Testing does have an important impact on students and teachers. Therefore, production of excellent tests, which assess attainment of desired instructional goals, is an area of work needing serious scholarship. This is especially true as we see new science assessment programs being implemented in many states. U.S. science educators must direct energy and influence toward the development of high quality tests if these state-wide testing programs are to have desirable results. Educators in other nations should also follow the advice given by Tamir in improving external examinations that are prepared by Ministries of Education and which have a strong impact on science instruction.

## Student Characteristics and Educational Outcomes

A substantial amount of research reported during 1985 examined relationships between a wide range of student characteristics and educational accomplishment. Included in this broad category are studies of predictors of achievement; cognitive, developmental, and affective correlates of achievement; and studies that add to our understanding of characteristics of students in particular populations, but which do not necessarily attempt to show relationships with educational accomplishments.

Within this section, the following sub-categories were used to organize the data (numbers of reports included in each sub-category are shown in brackets).

A. Predictors of Achievement: General, [15]
B. Cognitive Developmental Correlates of Achievement, [22]
C. Affective Correlates of Achievement Including Studies of Students' Attitudes. [17]
D. Factors Affecting Choice of Major and Career [5]

Within each section, studies are organized by age level of subjects, beginning with college age students and proceeding successively to high school, middle school, and elementary school students.

### Predictors of Achievement

The studies in this category explore a variety of predictors of achievement.

Armstrong (7) compared student characteristics and ACT subtest scores of students in 1975-76 and 1982-83. Gender, class rank, years of planned study in the four academic areas, and graduating class size were the independent variables. Subtest scores in English, mathematics, science, and social studies comprised the dependent variables. Of seven independent variables included in the analysis, class quartile ranking accounted for the greatest portion of variation in English, social studies, and natural science subtest scores. Years of planned study in mathematics accounted for the greatest portion of variation among mathematics subtest scores. As in most other studies, males tended to score higher on the mathematics, natural sciences, and social studies subtests than females while females tended to score higher in English. In 1982-83, females reported more coursework in natural science, but the mean subtest scores in this area did not vary significantly in comparison with 1975-76. Both males and females of 1982-83 reported significantly more coursework in mathematics, yet their mathematics subtest scores continued to decline.

Hurst (186) investigated the unique contribution of the amount of time allocated to the study of selected academic subjects at the high school level, as measured by the number of units completed in those subjects, to variance in subsequent academic achievement in those subjects as measured by American College Test (ACT) scores and college grades. Using a sample of 327 freshmen at a public college, data on high school grades, units earned, scores on Stanford Test of Academic Skills, and college grades comprised predictors. The results of regression analyses revealed that the number of high school units completed in mathematics, social studies, and science made significant respective contributions to variance in ACT mathematics, social studies and natural science subscores, and that the total number of academic units taken in high school contributed significantly to variance in ACT composite scores. In contrast, quantity of high school academic units did not significantly predict variance in college grades.

Hunter (183) examined predictors of achievement in General Biology courses in a predominately black university. Predictor variables were high school grade-point average; composite ACT scores and sub-scores in English, mathematics, social studies, and natural science; Nelson-Denny Reading Test total score; gender; student classification; and prior biology grade. Results showed that ACT composite scores and high school GPA were effective predictors of college biology grades.

DeBoer (102) studied correlates of success or failure of male and female students in their first collegiate science courses. Factors examined included personality variables of persistence, future orientation, the tendency toward reckless and rash behavior, and the direction of students' academic orientation as measured by the Ominibus Personality Inventory. Cognitive attributions for success or failure were also included. ANOVAs of level of success X gender showed no interactions for cognitive attributions or for direction of academic orientation. Interactions for persistence, reckless and rash behavior, and future orientation indicated that these factors were more important to the success in science for women than for men. Both men and women were more apt to attribute their success to effort and/or ability, while failure was attributed to the difficulty of a task.

Alcorn (4) examined relationships between problem solving styles as measured by the Myers Briggs Type Inventory (MBTI) and achievement in college chemistry. It was found that problem solving style does increase the variance explained by the currently used predictive tool. There is a non-simplistic relationship between problem-solving style as measured by the MBTI and achievement in college chemistry. The problem solving characteristics of successful and unsuccessful students, as well as those who withdraw, were documented. Some of the relationships coincided with, and others were contrary to, expectations based on the MBTI literature.

Rollins (322) studied the use of: (1) SAT scores, (2) high school rank relative to class size, (3) advanced placement status, (4) grades in high school science courses, and (5) grades in high school mathematics courses as predictors of success for freshmen college students in chemical and petroleum engineering. Data used in the study were collected from 307 entering students in the years 1972-77. Results showed the five variables listed above accounted for 54 percent of the variance in freshmen grade point average.

Craney and Armstrong (95) studied predictors of general chemistry grades among 304 students enrolled in tertiary level allied health programs. Predictors included scores on American Chemical Society's Examination, the Scholastic Aptitude Test in mathematics, and high school chemistry grades. The authors described ways of using of their results to identify students who are at a high risk regarding college chemistry grades.

Marsh (246) assessed the quantitative skills of students in two introductory college biology courses--one for prospective majors in biology and the other for non-majors. Relationships between quantitative skills, as measured by the Biomathematics Skill Test, and 15 student characteristic variables were also analyzed. Results showed that majors, males, and white students outscored non-majors, females and black students on the Biomathematics Skills Test. Predictors of success in the course for majors included mathematics and verbal SAT scores, high school GPA, age, and Biomathematics Skills Test score. Predictors of success for non-majors included Biomathematics Skills Test Scores and high school GPA.

Chadwick (75) conducted a correlational study of 178 British students who entered university study of physics and engineering between 1975 and 1981. Results showed positive correlation between achievement on A-level examinations and successful degree performance.

Rakow (312) drew upon National Assessment data to investigate the influence of student characteristics on the development of inquiry skills. Independent variables were selected from available data using the Model of Educational Productivity; the dependent variable was a 17-item measure of students' inquiry skills. Data showed that the Model of Educational Productivity can account for 24-32 percent of the variance for the general population of 17-year olds included in the study; whereas, general ability accounted for between 17 and 22 percent of the variance. For non-white students, the model accounted for only 18 percent of the variance in inquiry skill. Also, the model showed little difference in the predictors of inquiry skills for males and females.

Rakestraw (310) investigated the predictive values of mathematics and science standardized test scores as related to degree of success in a selected science/engineering preparatory high school. Rakestraw found that students who meet the admissions criteria of stated interest and a score at the 50th percentile or higher on the mathematics and language arts subtests of the Iowa Test of Basic Skills (ITBS) should have the ability to successfully complete the prescribed course of study.

In a study of chemistry students in grades eleven and twelve in Western Australia, Chadran, Treagust and Tobin (74) found that prior knowledge and formal reasoning ability were the best predictors of chemistry achievement, laboratory application skills and problem solving ability. Path analysis provided support for causal hypotheses linking laboratory application skills and problem solving ability with understanding of concepts, facts, and principles of chemistry.

Byerly (67) studied the attainment of scientific literacy by urban high school seniors using a path analytic model. The dependent variable was measured with a seven-dimension scientific literacy instrument. A wide array of independent variables was used including race, gender, SES, academic achievement, parental and teacher encouragement, and out-of-school science experiences. It was found that out-of-school science experiences constituted a more important predictor of scientific literacy than did in-school experiences. The model accounted for 53 percent of the variance for blacks, 58 percent for whites, 55 percent for females, and 67 percent for males. Compared to males and non-blacks, females and blacks were found to be less literate. The causal assumptions explained a large portion of the gender difference and a much smaller portion of the race difference. In general, female attainment was found to be much more dependent on the support of significant others, vocational-educational expectations, science self-concept, fate control, math achievement, and classroom psychological comfort. Science achievement motivation had a negative effect on female performance and positive effect on male performance. Performance of black students was found to be more dependent on in-school instruction and associated encouragements, and the quality of science instruction.

Greenfield (151) studied cerebral hemisphericity and its relationship to academic achievement, gender, and career preference of high school science and mathematics students. This study responded to concerns that our educational systems are biased in favor of the more verbal, analytic hemisphere (left) at the expense of the more visuospatial, holistic one (right), and that educational practices therefore should be restructured to accommodate the right hemisphere. High school biology students were taught for one academic quarter term, using methods based upon right- and left-hemisphere capabilities. Supplemental data were gathered by means of analyzing high school student hemisphericity scores in relationship to scores on a standardized science achievement test, and by surveying students in several adjacent high schools to determine whether or not hemispheric cognitive style could be related with sex or preferred college major. Hemisphericity of students was determined using Torrance's "Your Style of Learning and Thinking" questionnaire. Results indicated that, at least for the mostly-white, middle-socioeconomic class population of high school students from which study samples were drawn, there is a significant relationship between most of the variables. None of the main effects of instructional method, brain dominance, or sex, considered alone, effected a significant difference in student achievement. However, two-way interactions between all three of the independent variables did result in significant increases in student achievement.

Baker (15) examined the predictive values of attitudes toward science, spatial and mathematical abilities, and scientific personality on science achievement of middle school students. Results showed that males and females who earned grades of A or B in science demonstrated several characteristics of the scientific personality as measured by the Myers-Briggs Type Indicator. These students also had good grades in mathematics but negative attitudes toward science as measured by the Scientific Attitude Inventory. Males and females with C and D grades in science had more positive attitudes toward science but poor mathematical and spatial abilities. Gender differences on the Myer-Briggs Type Indicator showed that boys portrayed themselves as using logical analysis and girls portrayed themselves as using personal values in making decisions. No other gender differences were found.

Results of these studies showed that all of the standardized tests incorporated in them were effective predictors of science achievement.

Five studies explored gender as a predictor of success. It was a significant predictor in three studies. In the fourth, Baker's study, gender was related to MBTI results, but not to achievement in middle school science. Prior grades and prior study were significant predictors of success in two of three studies. A cause for concern lies in Armstrong's finding that even though students studied more science and mathematics in 1982-83 than in 1975-76, ACT scores continued to decline.

Barber's findings regarding the inverse relationship between attitudes and achievement among students in middle school science, and that gender was not correlated with achievement are of special interest. First, at the middle school level, have gender differences not yet begun to influence achievement in science? Second, what lies behind the observation that high achievers have negative attitudes toward science? Answers to these two questions have important implications for development of scientific literacy of the general population and for nuturance of scientific career choices.

## Cognitive Developmental Correlates of Achievement

Several studies included in this category focus on the relationship between students' learning ability and achievement.

A meta-analysis by Tamir (382) incorporated 54 research reports dealing with cognitive preferences and learning. The effects and relationships of cognitive preferences were examined along with important variables related to schooling. The findings of this meta-analysis: (1) supported the construct validity of cognitive preferences; (2) provided base-line data for comparative purposes; (3) showed that different cognitive preference tests have inherent biases; (4) indicated that cognitive preferences vary from one nation to another; (5) indicated that cognitive preferences vary among students of different ages; (6) suggested partial dependence of cognitive preference on subject matter; (7) showed a relation between the nature of the curriculum studied and students cognitive preferences; and (8) demonstrated a strong relationship between cognitive preferences and achievement.

Baird and Borich (14) compared and contrasted formal reasoning abilities and integrated science process skills using existing test instruments. Results of studies with prospective science teachers indicated that the two traits shared more variance than predicted and that they may not be distinctly different traits. Factor analysis indicated overlap of subfactors for controlling variables, probablistic reasoning, and combinational reasoning.

Hofstein and Mandler (175) appraised Lawson's Test of Formal Reasoning in the Israeli context to investigate the relationship between students' achievement in science and in mathematics, to compare performance of boys and girls, and to compare performance of Israeli and U.S. populations. Lawson's test was used with 66 ninth grade and 63 tenth grade students. Results showed boys outperformed girls; there was a small correlation between achievement in science and mathematics and the Lawson test; and Israeli students achieved significantly higher than did United States students on the Piagetian skills measured by the test.

Dennen (103) studied relationships between EEG alpha wave coherence and formal operational thinking, science grade point average, and selection of science as a college major. No linear relationship was found between 12 EEG alpha coherence measures taken during the TM technique and either cognitive performance or science GPA, except for one negative relationship between extreme frontal coherence and science GPA. Differences in EEG coherence were found among the college majors examined. The most obvious was the relatively high left, right, and frontal coherence among physics majors. The coherence patterns of art and math majors did not exhibit patterns consistent with current theories of brain functioning.

Rothaugh (325) studied the relationships between suburban community college students' use of logical connectives (and, or, if ... then) and science course achievement. Two measures were used; one was associated with students' ability to encode the connectives; the other was associated with the students' ability to make logical connections between propositions, using the connective words in addition to encoding. It was found that achievement was principally related to students' skill associated with encoding the connectives. However, many students appeared to place different logical meaning on the same connective which caused them difficulty in dealing with indeterminacy.

Niaz (269) evaluated formal reasoning skills of 709 freshman university students in Venezuela and determined correlations between formal reasoning skills and performance in several courses. Results showed that 84 percent of the students were operating at a concrete operational level and that achievement in chemistry had the highest correlation with formal reasoning skill. Mathematics, biology, biology laboratory, Spanish composition, English, and social science attainment all had decreasing correlations.

Costello (91) conducted an exploratory study of possible relationships between spatial skills, logical reasoning, and various genetics concepts with 21 students in an undergraduate genetics course. Her study showed that certain genetics topics are strongly associated with visualization skills, proportional schemata, induction, and disjunctive learning. It was also found that students' understanding of basic genetics concepts have common elements not measured by tests of visualization, logical thinking, proportionality, and flexibility of closure.

Richards (318) examined the relationship of cognitive development, cognitive style, and reading ability with academic success of community college students enrolled in a human anatomy and physiology course. One hundred thirty-one students majoring in health-related fields were tested using: (a) the videotape version of the Classroom Test of Formal Operations, (b) Group Embedded Figures Test, and (c) Comparative Guidance and Placement Reading Placement Test. Academic success was determined by students' performance on teacher-made examinations. The majority of subjects in this sample population were field dependent, functioned at the concrete operations level, and read at the fiftieth percentile or less. Cognitive developmental level, reading level, and field independence were all significantly and positively related to academic success.

Gipson (147) studied relationships between formal-operational thought and conceptual difficulties in genetics problem solving with 150 college general biology students studying Mendelian genetics. Students were given a unit test and, eight weeks later, a content validated posttest. Both tests required students to use proportional, combinatorial, and probabilistic reasoning in identifying gamete formations and zygote conbinations. All 150 students were given the Lawson Test for Piagetian intellectual development; 71 were given Piagetian interview tasks for proportional, combinatorial, and probabilistic reasoning. Pearson correlations, factor analysis, and analysis of variance results failed to show direct relationships among Piagetian tasks for the three kinds of reasoning and their corresponding occurrence in genetics problems. Mean scores on the post-test showed significant differences among the concrete, transitional, and formal thinkers in each of the three kinds of reasoning.

Gipson and Abraham (148) reported on the relationship between formal operational thought and achievement of 71 students in the genetics component of an undergraduate introductory biology course. Results showed that formal reasoning ability was related to unit test and post-test scores in the genetics unit.

Niaz and Lawson (270) examined the role of students' developmental level and mental capacity on 25 university students' ability to learn balancing of chemical equations. Two hypotheses were tested: (1) Formal reasoning is required to balance simple one-step equations; and (2) Formal reasoning plus sufficient mental capacity are required to balance many-step equations. Independent variables included intellectual development, mental capacity, and degree of field dependence/independence. Treatment consisted of two one-hour training sessions in which students were taught to balance equations using a trial and error method. Results showed that mental capacity correlated with capability to balance complex equations but not with simple equations. Field dependence/independence was not correlated with performance.

Stuessy (367) studied factors relating to the development of scientific reasoning among 106 middle and 96 high school students using path analysis methods. Results indicated that age and IQ were the strongest determinants of scientific reasoning ability followed by field dependence/independence, experience, and locus of control. Gender and rigidity/flexibility showed no significant relationship with scientific reasoning ability and a revised model, excluding these latter two variables, accounted for 61 percent of the variance in scientific reasoning.

Shemesh and Lazarowitz (344) examined the relationship between secondary school students' formal reasoning skills and other factors including learning ability, age, gender, and school type using a video-taped group test. Results showed (1) that boys surpassed girls in performance on the test of reasoning ability in grades 7-11, (2) half of the total sample of students was in the concrete operational reasoning stage, (3) percentage of formal reasoners increased with age, and (4) students in kibbutzim demonstrated a higher rate of cognitive development than did urban students.

Farrell and Farmer (122) used a sequence of proportional reasoning tasks in studying proportional reasoning abilities of a select group of college-bound adolescents. They found that even more able students required feedback and second trials to complete a multiple proportion task successfully. Significant gender differences were found in favor of male subjects in first order proportional reasoning, but there were no differences in multiple proportional reasoning. Prior course experience in mathematics and science were each significantly related to first order direct proportional reasoning, but no significant relationship was found between either of these variables and multiple proportional reasoning.

Falls (120) and Falls and Voss (121) reported on interactions of selected high school student aptitudes (developmental levels, field dependence-independence, and proportional reasoning ability) and their ability to solve chemistry problems with varying structure and information. Relationships of gender with chemistry problem solving and student aptitudes were also studied. Performance of students on chemistry quizzes constituted the dependent variable. With each quiz a number of in-task variables were identified: Piagetian logical structure (reversibility), algebraic format, type of information (relevant only or relevant and irrelevant), and nature of the information (explicit or implicit). Results showed that field independent students performed significantly better on certain in-task conditions. Degree of formal reasoning and proportional reasoning were found to be significantly correlated with success in chemistry, independent of the in-task conditions. Although males significantly outperformed females on proportional reasoning, significant interactions were found between sex and chemistry achievement.

Staver and Holsted (359) studied the effects of reasoning, use of models, gender, and their interactions on posttest achievement in chemical bonding after controlled instruction. Results indicated that students' reasoning capabilities influenced performance as did interactions among reasoning ability, gender, and use of models.

Fleming (130) investigated: (1) whether interactions between social and non-social cognition occurred as adolescents reasoned about socio-scientific issues; and (2) whether the form of reasoning used was related to the stage of social and non-social cognitive development. Interviews, the Test of Logical Thinking, the Defining Issues Test, and a Q-Sort comprised the data source on 50 high school students who had completed courses in both chemistry and biology. The Defining Issues Test and the Q-Sort were used to measure social cognitive development and scientific literacy, respectively. Findings demonstrated that: (1) There was no interaction between social and nonsocial cognition. (2) Social cognition dominated with moral reasoning being the dominant domain. (3) Salience effects seemed to influence the domain of reasoning used. (4) There was no statistically significant relationship between test scores and Q-Sort results and form of reasoning.

Zeidler (429) studied hierarchical relationships among formal cognitive structures and with principled moral reasoning. Using the "Test of Logical Thinking" and "The Defining Issues Test," measurements of formal reasoning and principled moral reasoning ability were obtained from 99 tenth-grade students. Results supported the notion of hierarchical relationships among specific modes of formal reasoning. Also, significant relationships were found between different modes of formal reasoning and principled moral reasoning with combinatorial and correlational reasoning accounting for 22 percent of the variance in principled moral reasoning.

Wavering (412) conducted a three-year study of middle and high school students to determine logical reasoning used to construct line graphs. Nine categories of student behavior were established ranging from "no attempt to make a graph" to "completed graph with a statement of relationship among variables." Students' behavior was interpreted using Piaget's developmental model. Response categories showed a close fit with Piagetian concrete operational structures for single and double seriation and formal operational structures for proportional reasoning and correlational reasoning. Interpretations provide useful information for teachers in understanding why students make specific errors in graphing and guiding instructional interventions.

Renner and Cate (315) evaluated use of formal reasoning skills by 22 high school biology students. Skills included combinatorial logic, correlational reasoning, separation and control of variables, exclusion of irrelevant variables, proportional reasoning, and probabilistic reasoning. Six Piagetian tasks and two questions requiring integration of subject matter and reasoning skills constituted the criterion measures. Results showed that students applied formal reasoning skills about 25 percent of the time in responding to the subject matter tasks requiring formal reasoning even though these students demonstrated their ability to perform the Piagetian tasks using formal reasoning skills.

Beaver (24) examined the development of the mental abilities of five- to nine-year-old children to separate and control variables. Twenty-seven children from each level (kindergarten, first, second, and third grade) responded to the three tasks. Those tasks were: (a) the Bouncing Balls Task, (b) The Footrace

Task, and (c) an adaptation of The Piagetian Bending Rods Task. Each of the tasks consisted of three levels of difficulty, commensurate to the number of variables. Using "fairness" as the criterion for judgment, children were asked to separate the variable(s) by recognizing the test as being "fair" or "unfair", he/she received one point. If the child could then go on to control the variable(s) by determining what changes needed to be made in order for the test to become a "fair test," the subject received an additional two points, achieving the perfect score of three. It was found that young children can begin to separate and control variables provided: (a) The tasks are presented concretely, (b) The content and materials are familiar, and (c) "Fairness" is used as the criterion for judgment.

What do these 22 studies show us? The studies reconfirm earlier observations that students capable of formal reasoning skills learn subject matter of science more readily than their peers who do not have these capabilities. They also tend to reconfirm gender differences in formal reasoning ability and give mixed results regarding its relation to achievement. The studies show relationship between cognitive development and specific tasks such as graphing, balancing equations, and analytical thought on genetics problems.

Shemesh and Lazarowitz's finding that several youth in the kibbutzim had a higher rate of cognitive development than did urban youth comes as a surprise. Another intriguing finding comes from Renner and Cate who showed that youth capable of formal reasoning only applied it about 25 percent of the time to tasks requiring higher order thinking. Both of these studies may serve as a foundation for significant research which explores underlying factors.

## Affective Correlates of Achievement

Scherz, et al. (332, 333) examined students' attitudes, expectations, and opinions about a desirable preparatory preacademic program before and after one year of science studies in the Preacademic School of the Hebrew University. Results showed that academically disadvantaged students expected the remedial work to teach subject matter and enhance learning skills such as scientific reading and essay writing. Students perceived these skills as having a greater influence on future success than did hard work or talent.

Lubbers (237) conducted an investigation to identify and characterize university students' attitudes toward technology as related to environmental problems. His findings showed that attitudes toward technology were reflected in students' course choices.

James and Smith (191) studied alienation of students from science in grades 4-12. Alienation is defined in terms of declining science subject preference and attitude scores of students (including blacks and females) in cross-sectional samples of adjacent grade levels. Using an instrument of their own design, over 6000 students in three districts in Kansas were assessed. Data showed that the greatest decline in students' attitude toward science occurred between grades six and seven. These data call into question the tendency to blame poor attitudes toward science on poor quality teaching during elementary school.

Talton and Simpson (379) studied relationships between peer and individual attitudes toward science of students in grades 6-10. Using their own test instrument which assessed students' attitudes toward science, as well as students' perceptions of their friends' attitudes toward science, the authors tested over 4000 students three times during one academic year. Results showed that the strength of the relationship between peer and individual attitude toward science increases significantly from grades 6-8 (peaking in grade 9) and that the relationship increases during the school year, such that, by the end of the year, there are no differences between grades.

Cannon and Simpson (69) studied relationships among attitude, achievement motivation, and achievement of 821 ability grouped students in seventh grade life science. Measurements of attitude, motivation, and achievement in life science were taken at three times during the school year using test instruments developed for the study. Results showed that science attitude and achievement motivation declined throughout the year, life science achievement increased, and differences in achievement motivation occurred between female and male students.

Simpson and Oliver (347) studied attitudes toward science and achievement motivation of 4000 students from grades 6-10 in a large school system. Newly designed attitude toward science and achievement motivation scales were administered to the students at the beginning, near the middle, and at the end of the school year. Results showed that positive attitudes and achievement motivation declined across grades and from beginning to end of each school year. Males demonstrated more positive attitudes toward science than did females. Females showed higher achievement motivation than did males. Few differences were noted based on racial background of students.

Lawrenz and Dantchik (225) investigated developmental and/or gender components of energy attitudes using Kuhn's Energy Opinionnaire. Students from grades 4-7 and high school participated in the study. Results indicated that changes in student attitudes through grade levels are consistent with cognitive and affective development literature and that gender differences are more pronounced in older students, with females having a more external world view than males.

Hasan (162) studied the influence of selected instructional, student, and home variables on 313 grade 11 Jordanian students' attitudes toward science. Attitudes were measured with an instrument constructed by the author utilizing the Thurstone-Chave Technique. Students' perception of their own science ability was found to be the only variable affecting attitudes of subjects. However, when students' gender is taken into consideration, data showed the importance of students' perceptions of two instructional variables -- science teachers' motivation and characteristics of text books.

Banu (16) studied attitudes toward science held by secondary school students in Gongola State, Nigeria. His findings showed that male students generally have more positive attitudes toward science than do female students. The type of school attended affect students' attitudes toward science, with students in special science schools having more positive attitudes toward science than students in general secondary schools. Female students in the single-sex school possess more positive attitudes toward science than did female students in mixed schools. The literacy status of parents, grade level of pupils, religion, and age do not have significant effects on the attitudes toward science of secondary school students in boarding schools.

Sousa (354) examined the relationship between a marine science survey course and coastal proximity, and the levels of knowledge and attitudes of marine science of high school students. Instruments developed for this study were; (1) a 42-item knowledge survey, and (2) a 27-item attitude survey. These groups of high school students were pretested early in the school year and posttested in April. Groups varied in proximity to the coast and participation in marine science instruction. Results showed that significant differences did not occur between the means of the three groups from pre to posttesting. Each of the three groups correctly answered approximately 46 percent of the posttest questions. This finding may be attributed to the fact that students acquire marine knowledge from sources other than formal marine courses. The coastal participants experienced a significant increase in positive attitudes. Coastal nonparticipants experienced a slight but insignificant increase, and the mean scores of the inland nonparticipants slightly decreased from pre to posttesting.

Napier and Riley (265) analyzed 1976-77 data from National Assessment of Educational Progress to examine the relationship between affective determinants and science achievement of 17 year olds. Results showed that motivation, anxiety, student choice, and teacher support accounted for most of the correlation between affective determinants and achievement.

Schreiber (335) examined factors affecting attitudes of females toward science. Her report includes an analysis of sociological and psychological theories and analysis of data on attitudes of 12-14 year old females toward middle school science. Schreiber concludes that the theories of operant conditioning and cognitive dissonance are helpful in explaining genesis of females' negative attitudes toward science.

Leithold (232) investigated the accuracy of male and female junior high school students' perceptions of parental figures' science attitudes and their relationship to students' achievement in science. The science related attitudes considered were those that the adults held toward the student as a science learner and those that the adults held toward science. Data indicated that the majority of students held inaccurate perceptions of the adults' attitudes toward the student as a science learner and toward science. However, the accuracy of the students' perceptions did not seem to affect the students' achievement. The student's achievement was influenced by the direction of the perceived attitudes. The students who perceived positive attitudes from the adults tended to have a significantly higher mean science grade than did their counterparts who perceived negative attitudes from the adults. In addition, perceived attitudes from the mothers and science teachers seemed to be more influential than were the perceived attitudes from fathers.

Bridgeman and her associates (54) studied the relationships between family environment and attitudes of seventh and tenth grade students toward science. Students provided assessment on two family subscales, family's science support and quality of family life. Family science support was found to be a significant correlate of positive science attitudes among students. Quality of family life was found to be an important predictor of attitudes for tenth-grade students but less important for seventh graders.

Ten Brink (385) studied fifth grade students' attitudes toward ecological and humane issues involving animals. Two hundred-sixty-eight students from two school districts were tested on three instruments regarding their attitudes toward ecological and humane issues involving animals. One-half of the sample acted as a control group. One-half of the sample received the treatment of caring for animals in their classrooms. All the students were posttested after a two month treatment period. All the students completed a biographical survey concerning gender, experiences with pets, and the frequency of zoo visits. Findings showed that males, pet owners, and children with access to live classroom specimens possessed more positive attitudes.

Beall (22) conducted a study to determine variation in science achievement of sixth graders which may be related to attitudes toward science, interest in science, science curiosity, verbal aptitude, quantitative aptitude, and nonverbal aptitude. A correlation matrix was constructed by multiple regression/ correlation analysis to examine relationships among the dimensions. Analysis of variance was employed to determine differences among study participants classified as high achievers, normal achievers, and low achievers in science with respect to attitudes toward science, interest in science curiosity, verbal aptitude, quantitative and nonverbal aptitude. Analysis of data showed: (a) significant differences among high, normal, and low science achievers in terms of interest in science, verbal aptitude, quantitative aptitude and nonverbal aptitude, (b) no significant differences among high, normal, and low science achievers in terms of science curiosity and attitudes toward science, and (c) verbal aptitude, quantitative aptitude, attitudes toward science, and nonverbal aptitude significantly related to science achievement.

Harty et al. (161) collected data on 293 fifth-grade students. Relationships between elementary school students' science achievement and their attitudes toward science, interest in science, reactive curiosity, and scholastic aptitude were investigated. Significant positive relationships were found between science achievement and all of the attitudinal tendencies tested.

Four studies demonstrated that students'attitudes toward science declined over the middle and high school years. Additionally, results of other studies showed that attitudes declined from the beginning to the end of the academic year. When these findings are coupled with Lubbers' data, which show that attitudes influence career choice, and with several studies which show a relationship between attitudes and achievement, a disturbing picture emerges. An array of questions also result including:

1. Can causal factors be identified which contribute to declining attitudes toward science among school age youth?

2. Can instructional conditions be altered so that attitudes do not decline? What are the "costs and benefits" of such changes?

3. To what degree are self-esteem and students' perceptions of their own abilities causally related to attitudes toward science as suggested by Hasan's results?

4. Are these effects real, or are they an artifact of the instruments and or methods used in this research?

The area of attitudinal research is in need of thoughtful reexamination since new studies appear to raise promising new questions.

### Factors Affecting Choice of Major and Career

Five studies were reported that addressed issues related to choice of a scientific major and/or career. Three of these studies focused specifically on gender-related issues.

George et al. (145) studied reasons university students chose chemistry as a major field of study. A ten-item questionnaire was administered to 554 students. Results showed the importance of secondary schools in spawning commitment to chemistry as a career.

Mondrinos (258) conducted a four-year longitudinal study of science majors as they progressed through the college science program. It followed a group of 688 students who had enrolled in an introductory biology course throughout their undergraduate experience. Student performance was examined over a four-year period to identify factors which influenced choices and success. Eleven entry and eight college variables were analyzed using discriminate analysis. Comparisons by gender and major showed that entry characteristics, freshman grade-point average, and success in chemistry are key influences in choice of major and in future achievement in science. Gender differences appeared to arise from differences in entry characteristics.

Kahle, Matyas and Cho (203) assessed the impact of science experiences on career choices of male and female biology students. Science experiences within and outside school were included. Results showed that boys and girls had similar classroom experiences, but out-of-school experiences were different which resulted in an advantage to boys. Results from this study, conducted in schools recognized for minimizing gender differences in classrooms, showed that girls held more positive attitudes toward science than were found in earlier studies of the general population.

Kahle (204) reported on a study conducted in seven states, during which teaching strategies and teacher attitudes which successfully encouraged girls in science were observed, described, and analyzed. Biology, taken by over 80 percent of high school students, was the course selected for observation; if girls are turned off to science in biology, they effectively close the doors to scientific or technological careers. Following a brief introduction, eight case studies of teachers who have had a "track record" of success with young women in science are presented. Teachers who are successful in encouraging girls to pursue science: (1) provided career information and informal academic counseling; (2) demonstrated unisex treatment in science classrooms; and (3) did not use sexist humor and did not allow boys to dominate discussion or activities.

Donovan et al. (109) studied the influence of science teachers as gender-role models for eighth grade girls. It was found that: (1) As gender-role models, the teachers did not enhance the science education career interests of their students. (2) The girls' career interest were not influenced by the gender of their teachers.

There were few surprises in the findings of these five studies. They point out that school experiences can influence choice of college major and, ultimately, choice of career. What do these results imply for further research and for changes in instructional practices? For the former, researchers who have specialized in this area will have to suggest new studies based careful analysis of their findings over several years. Regarding changes in practice, it appears that building opportunities for success for students and assuring equality of interpersonal treatment in classes are sound actions that can help assure that students will give scientific study and careers fair consideration. Beyond these common sense recommendations, a more thorough analysis of a wider spectrum of data is needed.

## Attitudes Toward Science

Nine studies were reported which pertained to attitudes toward science. One dealt with the development of an attitude scale, one report compared attitudes of teachers, administrators and parents toward science, two concerned science anxiety, and six examined the influences of instruction on attitudes.

Krynowsky (218) reported on the development of the Attitude Toward the Subject Science Scale (ATSSS). This report includes a substantial literature review on attitudes toward science, scientific attitudes, and methodological issues related to improving attitudes toward science as a school subject. A copy of the ATSSS Test, scoring instructions, and its theoretical background in the Ajzen-Fishbein theory of reasoned action are also included in this report.

Wagganer (404) surveyed parents of elementary school students and teachers and administrators in elementary schools in Missouri to compare their attitudes toward science. All participants responded to the 60-item Science Attitude Inventory. Parents were asked to place in rank order the school subjects taught at the elementary level and to assess and rank order four instructional scenarios. In addition, teachers were asked to report the frequency of use of different methods of instruction in their own classrooms. No significant differences were found in the three groups' attitudes toward science. Each group reported a low mean attitude score which was not significantly different from the others. No significant differences were found with respect to the age of the respondent, the educational level, the sex of the respondent, or with years experience. Teachers spent an average of 118 minutes per week on science instruction; their overwhelming choice of instructional method was teacher lecture/classroom discussion. Hands-on/experiment-type instruction occurred on a daily basis in seven percent of the classrooms. Parents ranked the hands-on/experiment-type of science instruction as the preferred method for use with their children. Teacher lecture was ranked least preferred of the four situations by the parents. Parents ranked the school subjects in the following manner from most important to least important to their child's elementary education: Reading, Mathematics, Spelling, Language, Science, Social Studies, Computers, Health, Penmanship, Creative Writing, Physical Education, Art, Vocal Music, and Instrumental Music.

Usera (398) conducted an assessment of science anxiety levels among adult learners in community college and university science courses. This study examined the influences of age, gender, educational level, and major upon the anxiety level of "adult" college freshmen. Using the Subject Anxiety Inventory results as the criterion, it was found that anxiety was significantly related to age, gender, and major. More importantly, it was found that help sessions reduced anxiety and improved retention rate among students, whereas, a control group who did not receive this support showed no change in subject anxiety and exhibited a low retention rate.

Hermes (172) compared the effectiveness of a science anxiety support group and a stress management program in the treatment of science anxious college students. Results suggested that science anxiety may be alleviated, but not eliminated by either stress management techniques or by a support group.

Kern (206) explored the enhancement of student values, interests, and attitudes in earth science laboratory through a field-oriented approach in a tertiary level general education course in science. Comparisons were made between two university classes taught by the same instructor using the two different methods. Pretest data on both classes for values (sense of importance), attitudes (sense of enjoyment), and interests (as related to the thirty major topics or themes of the course) indicated no significant differences between the two classes. At the end of the term, posttests on the same set of items revealed highly significant differences between the two groups. Students under the field-oriented approach left the course feeling much higher levels of importance, interest, and enjoyment associated with the learning experience than did students in the traditional lab. Cognitive gains were also evaluated using achievement on the final examination as the primary indicator. On the set of exam items testing recall of factual material, both classes exhibited almost identical performances. However, on the series of items requiring the synthesis of recalled material, the field-oriented class scored significantly higher, suggesting the possibility of better conceptual learning. Students in the field lab were much more willing to recommend the course to other students, and they also displayed a greater interest in taking additional courses in the earth sciences.

Saunders and Young (330) studied the effects of the presence and absence of living material in the high school biology classrooms. Dependent variables were achievement in biology and attitudes toward science. The treatment group held class in a room containing living materials, whereas the control group's classroom contained none. Students in the treatment group performed higher than control group students on both dependent measures. The findings were interpreted as suggesting that living materials in the biology classroom stimulated curiosity and interest which, in turn, influenced attitudes and achievement.

Johnson et al. (197) compared the effects of three different learning conditions (cooperative-controversy, cooperative-concurrence seeking, and individualistic learning) on motivation, achievement and attitudes toward the topic studied. Eighty-four fifth-grade students were assigned to conditions on a stratified random basis, controlling for gender and reading ability. In all three conditions, students studied whether wolves should or should not be a protected species. Data indicated that cooperative-controversy resulted in highest achievement, greatest motivation to learn about wolves, more positive attitudes toward wolves, and more positive attitudes regarding controversy.

Friend (138) assessed the influence of integration of mathematics and science in a seventh-grade physics unit on students' attitudes and achievement in science. Four classes, two at grade level and two above grade level in reading and math achievement, were assigned to treatment and control groups using a 2x2 design. The Science Attitudes Appraisal and a locally constructed Test of Physics Facts and Principles were used as pretest and posttests. Results showed (1) no difference in attitudes due to differential treatment, and (2) students at grade level and above grade level showed higher achievement resulting from the integrated format when contrasted with peers who received instruction in which science and mathematics were not integrated.

Studies by Usera and by Hermes provide encouraging findings regarding reduction of science anxiety. However, with only two studies reported, it is difficult to generalize. Further, the topic of science anxiety may be a promising one for a critical review of the literature as results of studies over several years may have important implications for practice.

The results reported by Kern, when coupled with those from Saunders and Young, lend support to a model of science instruction which many science educators support. That is, rich instructional environments resulted in better achievement and more positive attitudes among students. Practice appears to differ somewhat from this "ideal," however. Wagganer reported that while parents identified hands-on experiences as the preferred instructional mode in elementary science, teachers reported very limited use of this instructional approach, opting for lecture/ discussion more frequently.

Another of Wagganer's findings may require deeper interpretation than is possible here. Science was perceived as less important by parents than was reading, mathematics, spelling, and language, and more important than nine other subjects. I will leave it to others to determine if this is "good news" or "bad news."

As more instructional efforts are directed toward improved comprehension of the societal and technological consequences of science, Johnson's results take on increased importance. The cooperative-controversy mode of instruction appears to have desirable effects on students' achievement, motivation, and attitudes. People who are planning and implementing curricula which address societal and technological consequences of science should examine this work carefully.

Finally, Krynowsky appears to have made significant contributions in developing a new scale of attitudes toward science and in conducting a critical review of the literature on three interrelated topics. This work should serve as a basis for renewed activity regarding attitudes toward science and scientific attitudes.

## Students' Concepts and Conceptual Reasoning

Recently, the volume of research on students' conceptual reasoning and knowledge has increased. During 1985, 41 studies were reported that fit this category. To assist readers, these studies were classified into four sub-categories. (Numbers of studies in each sub-category are included in brackets following the sub-category name.)

A. Students' characteristics which influence attainment of science concepts. [4]

B. Studies of students' conceptual reasoning. [12]

C. Studies of students' concepts including misconceptions research. [15]

D. Studies of changes in students' concepts resulting from instruction, development, etc. [13]

E. The New Zealand Learning in Science Project. [16]

### Student Characteristics Influencing Concept Learning

Fields (123) reviewed literature to determine: (a) if instructional treatments could be identified that are effective in fostering learning of abstract concepts; and (b) personal and cognitive attributes that favor conceptualization. Areas reviewed included studies of concept achievement, cognitive learning style, cerebral hemisphericity, cognitive ability level, and gender. From this review, Fields concluded that: (1) There are no consistent methods for the teaching of abstract science concepts. (2) Most studies have ignored the individual differences of the learners. (3) Aptitude-treatment-interactions do exist for most, if not all, instructional strategies. (4) Certain cognitive attributes of the learner are more indicative of achievement than is the instruction provided.

Shepard (346) sought to determine if the cognitive demand considered necessary for solution of biology problems requiring concrete and formal operational thought was related to student understanding of biology concepts. To gain insight into this question, she examined relationships among conceptual understandings of concrete and formal biological science concepts, stage of intellectual development, and other background variables. The sample consisted of 77 eleventh-grade students enrolled in English classes. Results included different sets of discriminators for the level of conceptual understanding for the concrete and formal biology concepts. Significant correlations were found between both the formal and concrete concepts and all background variables, with the exception of age, for both classifications of concepts, and, with the exception of gender, for the formal concepts. All measurements of comprehension showed significant correlations with concrete and formal concept understandings. It was concluded that cognitive demand of biology concepts was related to students' comprehension of biological science concepts.

Harty, Hamrich, and Samuel (159) investigated the relationship between Concept Structure Interrelatedness Competence (ConSIC) and six cognitive and four affective variables. Data were collected for 105 middle-school students and treated by way of multiple regression, linear multiple regression and product moment correlation techniques. Results showed that concept structure interrelatedness and verbal scholastic aptitude accounted for the greatest amount of variance in predicting ConSIC. Other cognitive variables showed significant positive correlations with ConSIC. Positive significant correlations also surfaced among all affective variables.

Cothron and Thompson (93) studied student variables which influence attainment of ecological concepts and conceptual systems. Researcher-designed paper/pencil and free-sort categorization tests were administered to 256 Science Curriculum Improvement Study students in grades 4-6. Findings were: (1) Grade and ability, but not gender, influenced concept attainment and conceptual system. (2) Sequence of concept development was not influenced by grade, ability, or gender. (3) Sixth-grade students conceptualized life requirements, feeding relationships, food-mineral cycle, and community-environment interactions but not the higher-order classificatory concepts or oxygen-carbon dioxide cycle. (4) Discipline experts, not elementary students, possessed conceptual systems based upon higher-order concepts. (5) Concept attainment was promoted by a conceptual system similar to the discipline structure.

## Students' Conceptual Reasoning

Gorodetsky and Hoz (150) studied changes in cognitive structure of freshman engineering students enrolled in a general chemistry course. The study assessed students' cognitive construct of chemical equilibrium using a free-sort task that required classification of 21 concepts. Analysis was accomplished using Latent Partition Analysis, a multivariate technique, to examine changes before and after instruction. Their findings showed that this technique is useful in analyzing students' cognitive structure.

Chaiklin (79) studied university students' reasoning related to the concept of density. Results showed how reasoning is influenced by both relevant and auxiliary beliefs. Also, four characteristics associated with conceptual knowledge are discussed, including structural understanding, relations between mathematical and physical reasoning, misconceptions as revealed by errors in reasoning, and factors that affect the coordination of components.

Raven (314) examined lower-division college students' concepts of environmental problems by studying written and pictorial portrayals prepared as part of a class assignment. Students' work was analyzed using a three-category system that assessed: (1) the number of categories used by students in their description (differentiation); (2) the range of phenomena (discrimination); and (3) the interrelationships shown (integration). It was learned that the written work of students showed that the most used ability was discrimination and the least used ability was integration, suggesting that students were able to construct relationships among different environmental problems by using many types of environmental science concepts.

Maloney (244) investigated methods used by science majors and majors from other disciplines in making predictions about five situations involving conservation of mechanical energy, using a paper and pencil version of Siegler's Rule-Assessment Technique. Major findings of the study were: (a) 97 percent of the subjects in the study used identifiable strategies in responding to the task sets; (b) clear patterns were found in terms of rules used for various tasks; (c) usage patterns differed for science majors and majors from other fields; (d) sequencing of tasks affected the usage of the mass variable on tasks where it was irrelevant; and (e) it appeared as though the majority of students, including science majors, were working from a "heavier falls faster" concept.

Finegold and Mass (126) studied differences in processes of good and poor physics problem solvers in an advanced high school physics class. Using a sample of eight students, the researchers found that good problem solvers and poor problem solvers were significantly different in their ability in translating, planning, and physical reasoning, as well as in problem-solving time. No differences in reliance on algebraic solutions and checking problems were noted.

Finley (127) studied variations in high school physics students' knowledge about heat transfer prior to instruction on that topic. Data from interviews of students were subjected to propositional analysis and cluster analysis. A total of 359 unique propositions were used by students during the interviews. The average number of propositions used by each student was 39. Seventeen propositions were used by 90 percent of the students to explain an observed heat transfer event. Heat and temperature were equated by 16 percent of the students while 67.7 percent of those interviewed based interpretations of observation on a concept of "heat as something" and molecular motion.

Yarroch (427) utilized an interview technique in studying 14 high school chemistry students' strategies in balancing chemical equations. Results showed that students who could represent chemical equations diagramatically had a good understanding of balancing rules and the subscript concept, whereas those who were not able to construct diagrams consistent with the balanced equation had poor comprehension of these ideas.

Clough and Wood-Robinson (87) interviewed 84 British secondary school students (ages 12-16) regarding interpretation of instances of biological adaptation. Results showed poor understanding of principles, and wide use of teleological and anthropomorphic explanations. A recommendation is made for teaching evolution earlier as a way of improving understanding.

Tamir (384) studied twelfth-grade biology students' capability to distinguish between causal and teleological explanations. Assessment of 1905 students showed that their ability to distinguish between causal and teleological explanations was dependent on their knowledge of biology. Although the inability to make these distinctions contributes to misconceptions in biology, appropriate instruction can easily remedy the problem.

Lynch et al. (239, 240, 241) compared recognition of concept definitions by tenth-grade Hindi speaking students in India and tenth-grade English speaking Tasmanian students. Sixteen concept words relating to "matter" were described as simple textbook definitions and 16 multiple-choice items were constructed for each concept definition. Data from the two groups of students (n=826 and 1635 respectively) were compared from the point of view of development, performance for individual items, and overall performance at grade ten. Although mean score was identical for the two groups, there were differences on individual items and in overall development. Also, linguistic hypotheses were examined.

Flick (131) studied natural reasoning in children. Interviews with high-ability sixth graders were coordinated with an interactive Logo program which used turtle graphics to simulate the motion of an object on a frictionless surface. List-processing in Logo was used to record and later analyze the turtle behavior generated by the children. Data showed that children rarely used negatives, therefore, the transcripts contained few instances of inferences being explicitly tested or contradicted. Instead, the children used terms from analogies to relate an entire experience with a moving object, such as a balloon, a frisbee, or a car, to the turtle simulation. The computer record suggested that they held, but did not express the idea that an object should move in the direction of the most recently applied force. Computer analysis of turtle behavior suggested that improved control was achieved by two children through a shift in attention from the target position to the direction of motion. The children expressed multiple representations of the problem that were not necessarily compatible.

Cauzinille-Marmeche et al. (72) studied the influence of a priori ideas on the experimental approach of 31 French children, ages 11-13, investigating combustion of a candle in a closed container. Tasks included actual experimentation and interpretation of prepared data. Results showed that students preferentially experiment on factors about which they disagree and that the experimental method is considered as a proof method, which is consonant with the idea advanced in science classes. However, data spontaneously collected by children are not complete enough to test factors adequately. In addition, children used a very simple inference rule and frequently made explanations to suit specific cases rather than making generalizations.

### Students' Conceptions and Misconceptions

This sub-category contains a wide array of studies employing research techniques that vary from statistical methods to case studies. All appeared to hold a common intent of enlarging understanding of students' conceptual knowledge as an instructional antecedent. Nine of the fifteen studies in this sub-category were conducted by individuals outside the United States.

Smith (351) reported on his analysis of research which focused on the reasons students failed to understand science topics which they have studied in school. His analysis underscores the role of naive conceptions in causing students to interpret instruction in ways that are not anticipated by their teachers and also make it difficult for them to comprehend instruction. He points out that improvements in student learning can be attributed to a change in teachers' conceptualization of the teaching-learning process as that of helping students change from naive to scientific conceptions. Implications for teacher educators, teachers, and instructional materials designers are given.

Bishop and Anderson (44) examined conceptions of natural selection and its role in evolution held by prospective elementary teachers enrolled in a college level biology course. Three key concepts were identified: (1) origin and survival of traits in a population, (2) the role of variation in a population, and (3) evolution as the changing proportion of individuals with discrete traits. Results showed that virtually none of the students understood these concepts even though 88 percent of the students had studied biology for one year and 37 percent for two years prior to the course. On completion of the course, 53 percent, 57 percent and 63 percent of the students understood the three conceptions listed above.

Fisher (129) analyzed persistent error among introductory college biology and genetics students, namely, that amino acids are produced by genetic translation (protein synthesis). Sources of this misconception were revealed through analysis of responses to multiple-choice items and student interviews. Results suggested that four causes may underlie persistence of students' misconceptions and errors: (1) strong word association, (2) confusion generated by varied levels of generality, (3) conflict between dual roles of enzymes as "players and products" in protein synthesis, and (4) lack of knowledge about the origins of amino acids.

Vermont (401) noted several misconceptions related to tertiary level chemistry students' understanding of the mole concept and other fundamental concepts of matter. Her study is outlined more fully in another section.

Friedler et al.(137) identified students' conceptual difficulties in understanding concepts and processes associated with cell water relationships (osmosis), determined possible reasons for these difficulties, and pilot-tested instruments and research strategies for a large scale comprehensive study. Research strategies used included content analysis of commonly used textbooks, three paper-pencil questionnaires featuring 72 true/false items, and individual interviews based on two demonstration experiments. One hundred forty-two students in grades 9, 10, and 11 served as subjects. Among the findings are those indicating that: (1) Serious misconceptions exist among high school students and student teachers with regard to basic concepts such as solutions, solubility, particulate nature of matter, and molecular movement, and these misconceptions may well be among the reasons for difficulties in understanding osmosis and osmotic relationships. (2) Students use textbook definitions of osmosis and diffusion without fully understanding the concepts. (3) Teleology and anthropomorphism are widely used among students, as they provide causal explanations. (4) Certain textbooks (such as the Biological Sciences Curriculum Study textbooks) hardly mention osmosis. (5) The terms water potential, osmotic potential, osmotic pressure, and hemolysis are rarely dealt with in high schools. (6) The research instruments and strategies appear to be adequate and effective.

Clough and Driver (85) studied 84 students, ages 12-16, to determine their understanding about fluid pressure. Alternative frameworks were identified, along with implications for physics teaching, and the procedures and tasks used in acquiring and interpreting data.

Salyachivin et. al (329) used the interview-about-instances technique to investigate conceptual frameworks of 17 Fourth-Form (15-16 year old) students in Malaysia relating to the forces acting on objects at rest and in motion. Results showed similarity to alternative frameworks described by researchers studying youth in Western nations.

Villasmil (402) studied energy knowledge and attitudes of secondary fifth-year students in official high schools having both science and humanities majors in Venezuela. Using a newly developed instrument, containing 20 knowledge and 25 attitudinal items, she learned that students' scores on the knowledge items were very low, but they held positive attitudes toward energy conservation. It was also shown that science students were generally more knowledgeable than were humanities students on energy conservation and on energy issues. A "pollution" dimension and an "economic vs. personal" dimension were identified. Science students knew more than did humanities students on issues of pollution. Humanities students were less in agreement than were science students with regulation measures that affected them personally and economically.

Wiser and Martin (421) studied high school youths' concepts of heat and temperature as part of a computer-based intervention study. The project report characterizes students' naive conceptions of thermal phenomena. A report of the intervention study is included in the section of the report which deals with computer applications in science education.

Treagust (394) reported on the development of diagnostic tests to evaluate students' misconceptions in science. Tests were formulated and validated on the topics of covalent bonding, photosynthesis, and respiration.

Driver and Warrington (114) studied 28 academically able British high school students regarding their use of energy conservation concepts in solving written and practical problems. Interviews show problems they had in understanding and using the concepts of work and energy and that the idea of energy conservation was rarely used spontaneously in relevant situations.

Raat and de Vries (308) initiated a study of the conception of and attitudes toward technology using a combination of interviews and open-ended questionnaires. An 80-item Likert- scale questionnaire was formulated and administered to 3000 thirteen-year olds in the Netherlands. Fourteen factors were identified through factor analytic techniques. Results showed that: (1) Students think that technology is a broad, important, and not too difficult subject, but it is hard for them to say what it is and why it is not the same as physics; (2) Girls are less interested in technology than are boys; (3) Both girls and boys think that girls have the aptitude for technology; and (4) Students, whose father or mother has technical interests and background, are more acquainted with technology and are more aware of the importance of the field.

Biddulph (43) studied pupils' ideas about flowering plants among 7-14 year olds in New Zealand. He used an interactive technique including individual interviews of youth, a survey of 351 students, and whole class sessions to elicit students' questions. Results of these data-acquisition procedures are reported, including implications for teachers. Data showed that only about five percent of the students interviewed comprehended the life cycle of a flowering plant similar to a biologist's view.

Clement et al. (83) provided a descriptive analysis of adolescents' graphing skills based on clinical interviews with 25 seventh and eighth grade students. This study sought to determine: (1) the extent to which they could produce correct graphical representations of familiar situations; (2) to what extent they could infer relationships from graphs; (3) what are the most commonly held graphing misconceptions and how stable they are; and (4) the consistency of students' graphing skills across different content areas and types of problems. Notes taken from the tape-recordings of the interviews were used to identify the following types of misconceptions: graph as picture, slope/height confusion, centering on one variable only, linearity of scale, initial positioning at the zero point on the axis, and a static (rather than dynamic) conception of graphs. Two major misconceptions, both of which have been observed with college populations, were documented in the preliminary analysis of three items. The first misconception (graph as picture) was strongly exhibited in a bicycle problem (dealing with elevations and speed). For example, subjects drew a picture when asked to make a graph, and when presented a graph, they read it as a picture. The second misconception (slope/height confusion) was found in a problem dealing with graphs of temperature versus time of day.

Appleton (5) studied 8-11 year olds' ideas about hot and cold. Findings indicated that children's intuitive ideas about temperature and temperature changes of objects/events within their normal experience seemed fairly sound, that their subjective knowledge may influence what they actually "observe," and that their understanding of quantitative temperature did not match their understanding of qualitative temperature. In addition, children generally believed there was no difference between heat and temperature and that the greater the volume, the greater the amount of heat (or cold). These results are consistent with the findings reported in other research studies.

Biddulph and Osborne (38) explored children's ideas about metals. Data showed that nine and ten year olds have little enthusiasm for the topic of metals and most students have a restricted concept of a metal, exemplified by a large, heavy piece of steel; terms such as heavy, silvery in color, magnetic, and hard, typifies a metal object to most children.

Symington et al. (374) investigated 8-11 year old children's questions and explanations about rocks. The majority of questions raised by students focused on the formation, composition, location, color, and durability of rocks. Explanations can be categorized into looking for likenesses, linking different observations together, or using general ideas. The use of abstractions, however, was not noted.

Biddulph et al. (40, 42) and Osborne (285) reported complementary studies of 7-14 year olds' views about floating and sinking. Using the interview-about-instances technique, they examined children's concepts about the influence of material, depth of water, length of objects on floating and sinking. Meanings of the word floating and children's explanations of floating were also studied. Interviews revealed that different children attached different meanings to the word floating which in some cases differed from that of scientists. In addition, children had a range of views about why some things floated while others sank.

Hawe (167) investigated 8-10 year old New Zealand children's questions, interests, and ideas about spiders. Data were acquired in four classes and through interviews with 30 children. Interviews included children's ability to identify spiders and their ideas about features and functions of spiders. The report described several components of the data, including children's understandings, their meanings and ambiguities with vocabulary, their use of analogies, and the sources of their information about spiders. The author suggested that spiders would be a topic of interest to 8-10 year olds and that children's ideas can be a useful starting point to help increase understanding.

An earlier study by Biddulph (33) also examined children's ideas about spiders. Students were presented with a picture of a spider and were encouraged to ask questions and offer explanations. Questions raised by students were grouped into these categories: spider features; silk or web; food or prey; young or reproduction; species; poison; habitat; and origin, life, and death. Strategies used by children to gain ideas about spiders include guessing, generalizing from a limited experience, recognizing insufficient knowledge to form or offer an idea, recalling relevant past experiences, reasoning by analogy, and gaining ideas from such sources as books or television.

Placek (298) conducted an exploratory study to examine student-held concepts involving certain mechanical principles among gifted and non-gifted students. Gifted and non-gifted students included fourth graders who demonstrated concrete operational thought and eleventh graders who demonstrated formal operational thought as determined by a Piagetian test. The 14-item Perceived Knowledge Test was developed and administered to assess students' misconceptions of mechanics concepts. Results showed that students from diverse levels of age and intellectual ability shared common difficulties in dealing with mechanical concepts and that intelligence as measured by IQ scores does not facilitate students' understanding of fundamental mechanical concepts.

Smith (350) examined the problems associated with elementary children's understanding of density as an intensive quantity. Among the questions investigated in a pilot study with 28 children from grades one, two, and three were: (1) What naive theories do children hold regarding matter? and (2) Why do children have difficulty with the concept of density? Data reported from this pilot study showed that children had difficulty differentiating between weight and density, but the problem may be readily overcome through training.

Stepans and Kuehn (361) studied explanations of weather phenomena given during interviews with children in grades two and five. Children explained wind, clouds, thunder, lightning, rain, snow, and rainbows. Results indicated that most pupils in both grades were at a stage of nonreligious finalism and do not use true causality in explanations.

Bell (25) summarized research on elementary school children's ideas about plant nutrition including studies conducted at the Learning in Science Project in New Zealand.

### Conceptual Changes Resulting From Instruction, Development, etc.

This sub-category includes studies of conceptual change resulting from instruction in a controlled context and cross-age studies in which conceptual change may be attributable to instruction, development, out-of-school experiences, and other influences.

Roth (324) compared the effects of an experimental textbook and two standard textbooks on upper elementary school students' learning in science. The experimental textbook was designed to address specific misconceptions which were common among students as determined from earlier research. Results showed that students were more successful in relinquishing their misunderstandings in favor of scientific concepts about photosynthesis than were students using traditional textbooks. The author suggested that traditional texts provided obstacles to students' learning; whereas, the experimental text was sensitive to students' misconceptions, resulting in improved learning.

Happs (156) conducted case studies of students' restructuring of knowledge frameworks during instuction that was developed from a cognitive perspective on teaching. The report includes background information, comparison of teachers' intentions and students' responses and instructional implications.

Prather (303) conducted a philosophical examination of the problem of unlearning incorrect science concepts. The author suggested that learning the history of development of scientific concepts about which students hold misconceptions could help them reorganize and appreciate the inadequacies of their own ideas.

Watts (410) conducted a case study with one student regarding conceptions of the nature of light and optical systems. This study shows the importance of taking students' initial beliefs seriously, approaching issues through actual experiences, and using intelligible, plausible, and fruitful counter-arguments in order to bring about conceptual change.

Solomon (353) studied British high school students' comprehension of the principle of conservation of energy resulting from instruction. Preconceptions and changes in understanding were reported.

Terry et al. (386) studied British secondary school students' conceptual understanding of forces and static equilibrium during years 3, 4, and 5 of their study of physics. Emphasis was placed on preconceptions and changes resulting from instruction.

Griffiths and Grant (152) studied high school students' understanding of food webs. This research followed regular instruction in a biology class on the topic. Students were tested regarding their ability to determine how change in size of one population can affect another population in the same web, but not in the same chain. An individualized remedial treatment, based on their test errors, was given. The treatment involved activities at several levels of a hypothesized learning hierarchy. This was followed by a retest. Mastery of lower level skills in the learning hierarchy was noted in the initial testing but students exhibited little competence at higher levels. Following treatment, the proportion of students exhibiting mastery at all levels of the hierarchy improved. The authors also noted five major conceptual misunderstandings which affected achievement.

Barclay (18) employed micro-computer-based laboratories, which use probes to gather data on physical phenomena and enter it directly into a micro-computer as a vehicle to study and correct students' misconceptions regarding graphing. Initial results suggest that micro-computer-based laboratories can help in improving graphing skills. Attributes of the micro-computer-based science laboratories that seem important include: (1) the grounding of the graphical representation in the concrete action of the students; (2) the inclusion of different ways of experiencing the material (visual, kinesthetic, and analytic); and (3) the fast feedback that allows students to immediately relate the graph to the event.

Pines and Novak (297) studied the processes of concept acquisition by reviewing statements made by children before and after audio-tutorial instruction. A technique called concept propositional analysis was used to assess data acquired from case studies of two elementary school children. Results showed that new learning is linked to existing concepts and propositions, and in some cases, may result in elaboration of existing misconceptions. Audio-tutorial instruction, clinical interviews, and concept propositional analysis were found to be useful tools in studying children's conceptual structures.

Yager and Yager (425) studied understanding of eight science terms by students ages 9, 13, and 17 years in a midwestern school district. The eight terms were; volume, organism, motion, energy, molecule, cell, enzyme, and fossil. On three of the eight terms, 9-year olds performed as well as 17-year olds. Growth in understanding of five terms was noted between ages 9 and 13, but 17-year olds demonstrated little improvement and in some cases declined in understanding of terms. Gains in understanding are attributed to multiple factors, including improved reading ability and test taking skill over the age span, maturation, development of logical reasoning, and emphasis on content and terminology in instruction.

Arnaudin and Mintzes (8) conducted a cross-age study of students' conceptions of the human circulatory system. Using interviews with fourth graders and college freshmen as a basis, the authors developed and validated a fifteen-item test instrument to assess students' conceptions of the structure and function of the heart and blood, the circulatory pattern, circulatory/respiratory relationships, and closed circulation. The instrument was then administered to students in grades five, eight, and ten, as well as to college freshmen, including both biology majors and those majoring in other fields. Results showed that misconceptions tend to be persistent over time. Strategies to engender conceptual change are discussed.

Clough and Driver (85) studied British secondary school students' conceptions of heat conduction. Their work involving students at three age levels, described features of students' thinking about heat and temperature prior to instruction, as well as characteristics of older students' thinking. Results showed the persistence of students' existing conceptions in spite of instruction.

Trowbridge and Mintzes (396) studied alternative conceptions about animals and animal classification by interviewing fifth grade, eighth grade, and freshmen/sophomore college students. Subjects were asked to name five animals, state critical attributes, and complete a classification task. Results indicated all ages fail to generalize and discriminate among examples and non-examples of animals.

## The New Zealand Learning in Science Project

A cluster of papers are reported here which were produced by the Learning in Science Project at Waikato University in New Zealand. These papers were prepared between 1982 and 1984 and were not included in earlier annual reviews. The papers focus on elementary and middle school science for children ages 7-14 years of age.

For purposes of this review, the papers have been grouped into three categories as follows: (1) general background papers, (2) reports on children's conceptions on a variety of topics, and (3) reports on instructional interventions with teachers.

Reports for categories 1 and 3 follow. These reports not only provide a useful source of information about the character of the Learning in Science Project, but they also constitute a record of development of a large-scale research and improvement program in science teaching.

Reports for category 2 were included in the earlier section entitled "Students' Conceptions and Misconceptions." These reports represent a substantial addition to the literature of that area of inquiry.

### General Background Papers

In category 1, seven background papers are included which describe the character and initial findings of this project. These papers provide a foundation for subsequent work reported in categories 2 and 3.

Biddulph (31) reported on a study of the views of science held by New Zealand elementary teachers, principals and children. Data were collected through unstructured interviews. The report focused on children's learning and teachers' teaching science.

In another related study, Biddulph (32) examined classroom practices of four experienced elementary teachers as they worked with 90 students ages 5-11. The report describes difficulties in teaching and learning science and contains two parts which focus on: (1) six issues related to teaching, such as teacher-centered lessons and teachers' assumption that students' meanings for words were correct; and (2) issues related to learning including children's questions, children's communication of ideas, changing ideas, understanding things, answering strategies for teachers' questions, and strategies when doing activities. One conclusion noted (which supported previous data) was that teachers perceive their role in primary science teaching as one of transmitting knowledge to children.

Symington et al. (377) provided a conceptual framework for organizing research and development for the primary school component of the Learning in Science Project.

Osborne et al. (286) formulated a working paper which encapsulated initial research findings from the primary school component of the Learning in Science Project. This paper reported on teacher-related and student-related difficulties in elementary science. One finding, that appears to underscore much current work, pertains to the stability of children's ideas. Osborne and his associates stated that children have strong views about topics prior to learning, that these views are often different from scientist's views, and that these views often remain uninfluenced, or are influenced in unanticipated ways, by science teaching. This paper also contains summaries of six Project reports.

Symington et al. (375) reported on procedures for explaining pupils questions about, and view of, the world as a fundamental step in planning a science program that focuses on their present interactions with the natural world. Children's questions, efforts at probing children's thinking, and instructional reforms are included in this background report.

Biddulph and Osborne (36) reported on analysis of initial studies at the elementary school level based on children's questions and explanations. This work suggests that elementary school children can identify a communication system which encourages them to ask questions, are able to decide which questions interest them most, will accept questions which are not their own, and appreciate lessons based on their questions. In addition, variations in the number of questions asked by children and in the number of children asking questions were found. Other findings reported include: (1) features of children's questions (such as questions serving different functions for different children); (2) six aspects of children's explanations (including the finding that children's answers give insight into the way they interpret a question); and (3) teachers' reactions to science as inquiry (such as teachers being surprised at the sophistication of children's questions and answers).

Biddulph et al. (37) also reexamined and extended the procedural framework guiding the Learning in Science Project. The extended plan includes use of the "interview-about-instances" method to determine children's ideas on various topics and the use of a proposed teaching model to guide research, instructional activities, and development of teaching guides.

### Instructional Intervention With Teachers

Nine papers which comprise this category range from a description of a model to reports of school-based research on interventions with teachers to improve instructional effectiveness in elementary school science.

Harlen and Osborne (157) provided a description of the teaching model to be utilized as part of the Learning in Science Project. The model utilizes children's questions and explanations as a basis for an alternative teaching approach. This paper examines issues related to the proposed model including the following points: (1) What should a model include to be both internally consistent and consistent with a particular view of learning? (2) How may a generative model be designed to help children develop ways of exploring and viewing the world around them which considers learning experiences and the roles of learners and teachers, and also examines the evaluation criteria to be used? (3) What constraints exist related to the proposed approach? (4) How should instructional sequences be organized? (5) How can instructional content be related? (6) How may teachers be encouraged to adopt the suggested new approach?

Biddulph and Osborne (41) produced a booklet entitled Children's Questions and Science Teaching: An Alternative Approach which outlines strategies for helping children with investigations based on their questions about a topic. The theoretical framework of this guided is related to specific examples from research on 9-13 year old children's thinking about floating and sinking.

Biddulph et al. (40) provided some additional teaching suggestions on floating and sinking in a booklet prepared for teachers who need extra guidance in teaching this topic. The booklet provides background information using both scientists' and children's ideas about floating and sinking and suggests a variety of investigations and projects for use in class.

Symington (373) reported on a formative evaluation of the booklet described above. Analysis included (1) unit objectives (which are not stated formally in the unit); (2) time allocation (not specified in the unit); (3) vocabulary; (4) definitions; (5) scientific background; (6) emphasis placed on teachers knowing about the ideas their students bring to their lessons; (7) sequencing of activities; (8) model of science; (9) attitudes toward the learning of science; and (10) instructional strategies. Authors of the materials were asked questions regarding their rationale for specific choices made. Responses to their questions are also reprinted.

Biddulph and Roger (35) reported on a study of a beginning teacher teaching a unit on seeds. The model of instruction emphasized children's questions, explanations, investigations, and reporting as a basis of elementary science teaching. Students' responses and the teacher's thoughts and feelings about the approach, its difficulties, and its perceived advantages are analyzed and reported. The advantages include fostering positive attitudes toward science and providing insight into children's ideas and views of the world about them. In addition, information was provided on what children regarded as important and interesting about seeds and their prior knowledge of the topic.

Biddulph and McMinn (39) reported on a similar study of teachers using the same approach to teach a unit on the topic of metals.

Symington and Osborne (376) analyzed reasons for limited implementation of science programs by elementary teachers using data from the Learning in Science Project. They outlined seven areas of concern which tend to restrict teachers' development in science, including: (1) limited science background, (2) over-reliance on inquiry teaching, (3) classroom management, (4) materials management, (5) evaluation, (6) content selection, (7) teachers' ability to influence children's ideas. A description is provided of an approach to promote teachers' professional growth in the teaching of science so that they can move from these concerns of self to concerns about learners. Science programs are proposed which allow teachers both to cope effectively and to focus on children's thinking about natural phenomena. The current research is exploring the practicality and the potential of these proposals.

Appleton et al. (6) studied the effect of two booklets designed to enable teachers to conceptualize their teaching role from didactic, activity-driven teaching to conceptual-change teaching. Booklets differed in the degree of guidance given to teachers in helping elementary school students understand floating and sinking. Each booklet was evaluated during six 25-45 minute lessons over a two-week period to determine the extent to which the authors of the booklets were able to convey their intentions to the teachers. The problems encountered by teachers during the lessons were also studied. Data were obtained from student interviews and from a comparison of suggested strategies in the booklets and actual classroom practices. Findings showed that actions of the teachers matched the authors' intentions in some respects but departed from them in others and that use of the guide was influenced by the teachers' views of teaching and children's learning processes.

Biddulph et al. (42) reported on studies in which they used two booklets to help teachers adopt conceptual-change teaching strategies. Case studies of teachers in the process of altering teaching approach are included in this report.

Well over ten percent of the research reported during 1985 is encompassed by this category of students' concepts and conceptual reasoning. Even with more than 50 studies in this category, it is difficult to make generalizations because the studies range over such diverse topics and research questions.

There were some disturbing findings. Field's analysis of research literature showed that (a) there were no consistent methods for teaching abstract science concepts in research studies and (b) learner characteristics were more critical than instruction in determining achievement. These findings appear to imply that treatment modalities in science education research are in serious need of development and refinement. Perhaps researchers need to give much greater attention to instructional treatments as part of research design than has been the case in the past. For many years researchers have given attention to assembling valid and reliable test instruments. It would appear that instructional interventions may need similar scrutiny and standardization if meaningful progress is to be made in this area.

In a slightly different vein, but equally disturbing, is the apparent persistence of students' misconceptions. This appears to be a recurrent finding in the research reported here and in other studies reported earlier. Why is it that students' ideas are so resistant to change, especially regarding some of the most fundamental concepts of science? How can instructional treatments be made more effective in changing students concepts?

Promising work in conceptual change teaching is reported. However, this research area is at its initial stages and thoughtful development is needed if it is to reach its potential. Science educators will benefit from collaborative work with cognitive psychologists, appropriate discipline-based scientists, and with specialists in research on teaching and teacher education in developing this area and achieving the potential that it appears to hold.

Studies of students' concepts and conceptual reasoning also are needed to enrich our background and understanding as a necessary prerequisite for conceptual change teaching. However, these studies must provide more than identification of the concepts and conceptual thought patterns of students of various ages. The research must also examine factors which underlie students' concepts and thought patterns to help formulate a picture of the ontology of concepts and conceptual reasoning.

Such knowledge will serve as an important foundation in changing science teaching from a craft stage to a more scientific (or engineering) type of enterprise.

## Instructional Treatments and Student Achievement

Fifty-eight studies were reported during 1985 which examined the relationships between various instructional treatments and student achievement. These studies ranged from explanation of instructional treatments at all levels, elementary to college, with the substantive content ranging across disciplines and applied fields. In addition, studies of science instruction for gifted students and non-formal science education are also included in this section. Research methods included secondary analysis and meta-analysis of data bases, literature reviews, and experimental studies of the effects of specific instructional strategies on students.

The organizational scheme for this section of the review is as follows (numbers of papers in each section are shown in brackets):

A. General Studies [8]

B. Tertiary Level Studies [16]

C. Secondary Level Studies [13]

D. Elementary Level Studies [7]

E. Science Instruction for Gifted Students [5]

F. Non-formal Education in Science [9]

Studies are arranged by educational level, from tertiary to primary. The interpretation, however, cuts across levels, somewhat, to examine studies of related questions.

### General Studies

Spade et al. (355) explored school characteristics which influence students' performance in science and mathematics. The research strategy altered prior models in two ways: First, schools were examined in terms of the school context, that is, whether the student body is predominantly of high-ability or low-ability. Second, differential effects upon individual students of different ability levels were also considered. Empirical analyses using the High School and Beyond data showed that schools do influence mathematics and science performance, primarily through ways of influencing enrollment patterns. The curricular organization of schools and the academic encouragement given to students were found to be essential elements in enhancing students' performance in science and mathematics.

Hamilton (154) assessed performance levels of 1146 grade eleven Jamaican students in science and other academic subjects. Comparison between achievement of students in co-educational and single-gender schools showed that students from co-educational schools had lower performance on all measures. Discussion of the results focuses on gender role and other factors to which the observed differences may be attributed.

Trout and Crawley (395) studied the effects of matching instructional strategy with selected student characteristics. Independent variables included need level, cognitive style, and locus of control. Attitudes and achievement were dependent variables. Using a quasi-experimental design, 301 and 273 ninth-grade physical science students constituted the experimental and control groups, respectively. Pretests were used diagnostically and instruction for the control group was matched to students' characteristics in whole class settings for 21 days. Findings implied that attitude toward science improved with matching, but achievement and attitudes toward physical science, the teacher, and instruction did not improve.

Curbelo (100) conducted a meta-analysis of 68 experimental studies to determine effects of problem-solving instruction on science and mathematics student achievement. Results showed that instruction in problem solving produced a mean effect size of .54 standard deviations over no instruction in problem solving in enhancing student achievement. Additional analysis showed that instruction in problem solving of 5-10 weeks duration was most effective. When instruction lasted more than 20 weeks, negative results were noted. Also, results suggest that problem-solving instruction is independent of particular content.

Clark (81) reviewed literature on individualized science instruction and its effects on student achievement and attitudes. Her findings showed: (1) that differences among students require different types of science instruction, (2) inconclusive results when research on individualized instruction and academic achievement was examined, (3) positive effects of individualized instruction on student attitudes in all but one study, and (4) need for teacher training as a necessary component in the effective introduction and management of individualized instruction.

Donnellan and Roberts (108) summarized changes in student achievement and behavior in cross-racial settings due to adoption of an activity-based elementary science program. Hands-on experience in mixed-race groups was effective in student learning and enhancing integration.

These six studies deepen our understanding of the relationships between school and classroom conditions and students' achievement. The curriculum and school organization, inclusion of specific instructions in problem solving, and hands-on experience all influence students' learning of science in school. However, Trout and Crawley's finding that matching instructional strategies and student characteristics did not influence achievement came as a surprise. This finding, as well as Field's study reported later, is counter-intuitive and suggests the need for further research to determine if altering matching criteria and treatments will yield different results.

These studies present a rather fragmented picture due to their diversity. Critical analysis of research relating achievement to topics such as school organization, classroom characteristics, or instructional content is needed in order to draw conclusions that are worthy of changes in policies and practices. Such an analysis, obviously, would draw upon research studies from a broad time span. Welch's synthesis (415) is an important step in this effort.

The studies which follow shed more light on specific issues relating to instructional literature and students' achievement.

## Tertiary Level Studies

Frank and Herron (134) studied the effects of using a problem-solving technique as part of recitation sections in an introductory chemistry course. The problem-solving method employed in this study included heuristics, three modes of representing problems, and a three-phase approach to solving problems. Comparisons between problem-solving strategies of students taught these methods and those experiencing only direct solution of chemistry problems was achieved by analysis of transcripts of selected students as they worked problems aloud.

Horton et al. (180) studied the effect on achievement of writing summaries of college chemistry lectures. Sixty-four students were randomly assigned to two groups. Treatment group members were required to submit written summaries of eight class lectures. Summaries were graded and returned with mistakes noted in chemistry and writing. Feedback on errors in chemistry content of reports was shared with the entire class prior to the posttest. Analysis of posttest results showed that treatment group members scored significantly higher than did control group members. While writing assignments and feedback appear to enhance achievement, this study did not control for added time required to write summaries.

Bunce (60) compared the effects of an explicit problem-solving approach to problem solving in college chemistry with a dimensional analysis approach. The explicit approach was based on an information-processing model of problem solving. Achievement of the two groups was measured during three scheduled hour tests and the course final examination. No significant difference was found at the .05 significance level in the mathematical chemistry achievement of those students who received instruction in the explicit problem-solving approach and those who were taught dimensional analysis as their problem-solving approach. The control group's pretest scores showed a significantly higher correlation to achievement scores than did the treatment. A significant negative correlation was found between pretest scores (Logical Mathematical Reasoning Test) and extent of explicit problem-solving approach use within the treatment group. One inference to be drawn from the study is that training in the explicit problem-solving approach helped less able students with chemistry achievement.

Bradford (52) conducted a study to ascertain if providing course objectives in the form of multiple-choice quiz questions could enhance student performance on a final examination and if referring students to a specific lecture and textbook passage could circumvent student misunderstanding of instructional intent. Results showed that administering course objectives in the form of both multiple-choice pretests and posttests coupled with referral to specific course materials can enhance student performance of a standardized final examination in college chemistry.

Vermont (401) compared the effectiveness of three instructional strategies on tertiary level students' learning of the mole concept and alteration of related misconceptions. These three strategies were the learning cycle, a cognitive learning and development strategy, and a lecture-laboratory strategy. Instruction continued over five weeks for all three groups. The results of this study indicated that for this sample the three methods were equally effective when used to teach various aspects of the mole concept. The results further indicated that the three methods were equally effective in bringing about conceptual changes in which knowledge concerning mass, volume, and the particulate nature of matter matched the knowledge structure of experts in this area.

Widing (419) compared college students' learning of the isomer concept using a method derived from concept analysis and a traditional approach. Students who were given a diagram summary, derived from the concept analysis technique, scored significantly higher than their peers taught by a conventional approach in both posttest and five weeks after treatment.

Using a questionnaire technique, Schomer (334) investigated the perceptions of nursing educators and practicing nurses regarding the chemistry content desirable for pre-nursing students. Results of the survey were used to formulate a "condensed" chemistry course for prospective nurses. This course was compared with the standard introductory chemistry course using a general chemistry examination and course grades in organic and biochemistry as dependent variables. Results (1) suggest that the condensed general chemistry course was somewhat more effective than the "regular" general chemistry course in teaching chemistry concepts prerequisite for the organic and biochemistry course and needed by nurses, and (2) demonstrated that prenursing students in the condensed general chemistry course were as well prepared for the organic and biochemistry course as those in the "regular" general chemistry course.

Otto (289) also studied the effect of writing as a process with writing as a product on the written communication skills of undergraduate students enrolled in a preservice physical science course for elementary school teachers. Subjects wrote papers on experiments. The control group received grades but no written feedback; whereas, the experimental group received both grades and feedback. A personal writing sample was used as a posttest, following a semester-long treatment. Results obtained from analyses of these papers show no difference in writing competency between experimental and control group students.

Omasta (282) studied the cognitive and affective effects of incrementing variables of selected physics functions with the aid of hand-held calculators in a university level physics course. Results showed that problem-solving skills are enhanced when the exploration of functional relationships is emphasized.

Stevens (262) studied the effects which concrete analogies have on learning by college students. A computer program, two biology lessons, two concrete analogies and a set of test questions were developed specifically for use in this study. The results

**indicated a possible significant effect for retention of application level ability for concrete lessons. This study underscores the need for more research on the effectiveness of analogies in augmenting learning.**

**Shapiro (340) reported a study of analogies and visualization on mental processing of college students who were assigned to an analogy treatment and a visualization treatment. Findings showed that the analogy treatment group required less cognitive capacity and the visualization treatment required more cognitive capacity to process the materials. The analogy results support the theory that analogies make mental processing more efficient by modifying the existing cognitive structures prior to processing the new information. The visualization results support a theory that visualizers devote more attention to the material being processed.**

**Johnson (194) investigated the effects of using concrete analogies on formal and informal operational nursing students' learning of physiological and pathophysiological abstractions. Sixty-five volunteer nursing students participated in the study, 38 of whom were judged as less than formal operational, using the Classroom Test of Formal Operations. Subjects were randomly assigned to the experimental group or the control group. Each group has subgroups of non-formal and formal operational subjects. A pretest/posttest design was used. The experimental group were taught using slide-tape presentations which included concrete analogies representative of selected abstractions. The control group also had slide-tape instruction but without the concrete analogies. following instruction, a posttest was administered. Results showed that students in the treatment group scored significantly higher than the control group on the posttest. However, formal operational students in the experimental group did not perform significantly higher than formal operational students in the control groups. Results also showed that there was no significant difference in the performance of the non-formal operational subjects in the experimental group compared to the formal operational subjects in either the experimental or control group. Therefore, concrete analogies were shown to be an effective teaching strategy for non-formal operational students.**

**Johnson (198) and Johnson and Lockard (199) investigated the effect of kinetic structure and micrograph content on achievement in reading micrographs by college biology students. One hundred introductory college biology students attended three audiovisual presentations and three micrograph practice sessions on reading light, transmission electron, and scanning electron micrographs.**

High-kinetic structure instruction is more effective than low-kinetic structure instruction in developing general concepts about micrographs. This finding supports Anderson's kinetic theory research. Although high-kinetic structure instruction does not affect actual reading micrograph skills, micrograph content does. Unified micrograph content practice sessions are more effective than varied micrograph content sessions in developing actual reading micrograph skills.

Haukoos and Penick (165) examined the effect of discovery and non-discovery classroom climates on college students' learning of science process skills and biology content achievement. Results indicated that students in the discovery climate learned as much content as students in more direct class.

Scherz et al. (332) described a Hebrew University program for academically disadvantaged students, focusing on a workshop component which emphasized learning skills and study strategies. An evaluation of the workshop indicated that it led to improved achievement in several academic fields including the natural sciences.

Two studies which examined writing in science had different aims and results. Horton et al. found writing with feedback was useful in improving achievement in college chemistry while Otto found that writing experiences did not improve students' writing competence. Horton's results were questioned on the grounds that time-on-task was not controlled. However, writing may be an effective vehicle to increase the amount of time students devote to study of chemistry. Thus, what was identified as a design flaw may be a practical benefit to college chemistry instructors.

Two studies, one by Bunce, and one by Johnson, appeared to show the possibility of diminishing the disadvantage of less able students in college chemistry. Analogies and explicit instruction in problem solving appeared to aid less able students in achieving at a level more nearly like that of able students. A study by Burns and Okey reported in the next section shows similar results in high school. Schomer also found that a "condensed" course in general chemistry was more effective than the standard chemistry course in teaching prospective nurses needed chemistry concepts. Wilding's conclusion that concept analysis improved achievement on a college chemistry topic conforms to earlier findings. This appears to be a strategy that could be used to improve instructional effectiveness.

These studies suggest that carefully designed instructional treatments not only influence achievement, but can eliminate at least part of the deficit which some students bring to tertiary science classes.

## Secondary Level Studies

In a study framed on Maslow's hierarchy of needs, Crawley and Trout (96) examined the cognitive and affective characteristics of students entering a ninth grade physical science course. They appraised the effects of a three-week instructional unit designed to meet locus of control and cognitive style needs of students whose physiological and safety needs had not been met. Significant differences were found in the cognitive and affective entry characteristics of students of differing need levels. Students differed in their attitudes toward science in general and in their prior knowledge of physical science. Matching of instruction with students' physiological and safety needs was not beneficial for students primarily concerned with fulfillment of low needs. However, differences in achievement were found to be dependent upon the extent of matching, but, surprisingly, matching did not influence students' attitudes.

Imenda (188) reported on a study of the transferability of selected concepts and procedures of scientific experimentation beyond the context in which they were acquired. For the purpose of this study both content-specific and general-knowledge learning contexts were defined and subsequently examined. Instructional materials were developed to present selected experimental concepts and procedures to students in each of these contexts. Subjects were 342 students from single-gender schools in Zambia. The results of this study showed that instruction in the cognitive aspects of the selected concepts and procedures of scientific experimentation resulted in the students ability to transfer such knowledge to a situation outside the context within which the instruction was presented. The results showed, further, that instructional materials in the general-knowledge context provided for a significantly higher level of transfer than did the content-specific context.

Omar (281) investigated the effect of using diagnostic-prescriptive teaching on achievement in science of Saudi Arabian high school students. Following diagnostic testing of half the research population, three levels of remediation were administered to the six groups: (1) teacher-directed, (2) student-directed, and (3) lack of remediation. Both testing and remediation produced significant differences in student achievement. However, interaction effects were not significant.

O'Brien (274) described and investigated personalities, selected behavioral characteristics, educational interests, and influence of science-oriented secondary students who chose to participate in three types of science enrichment. The different instructional settings included the structured, formal classroom; the environmental field; and the research apprentice laboratory. Results showed that students who chose to participate in the research apprentice setting have different educational backgrounds and interests compared to students who chose to participate in other forms of enrichment. The students across instructional settings evaluated each of the following enrichment experiences favorably; lab experiences, academic knowledge gained, interaction with staff/professors, receiving college credit, and career awareness.

Idar and Ganiel (187) reported on the development of a remedial teaching method for introducing high school physics and assessed its impact on achievement of Israeli students. Preliminary developmental work included a task analysis of cognitive entry requirements and assessment of students to identify specific difficulties and misconceptions which were affecting students' performance. Using this information, a remedial teaching method was developed and implemented. The method involved immediate feedback and corrective teaching. In an assessment of the effects of this program in a large number of schools, using experimental and control group design, the experimental group demonstrated higher achievement. In a statistical analysis, the models accounted for 47 percent of the variance in achievement with 16 percent due to the treatment effect.

Lazonby et al. (228) explored differences in questioning format on secondary school students' learning the mole concept in chemistry. Two tests were administered to 652 students to investigate the effect of structuring questions about the mole. A third test was administered to see whether each step/operation was intrinsically difficult or if it was only difficult when part of a series of steps/operations.

Renner, Abraham, and Birnie (316) investigated the influence that changing the form of the learning cycle's exploration/expansion phases had on the content understandings and attitudes of high school physics students. The naturalistic data presented showed that students believed learning physics is enhanced by the regular-form learning cycle which focuses on laboratory activities even though alterations of form did not alter achievement. The authors also attributed increased enrollments in physics to use of the regular form of the learning cycle.

**Lederman** (229) and Lederman and Druger (230) examined classroom factors related to changes in students' conceptions of the nature of science. Eighteen high school biology teachers and 409 students in their classes were studied. Classes in which students exhibited the greatest conceptual changes toward their teachers' viewpoint were typified by: (a) frequent inquiry-oriented questioning with little emphasis on rote memory, (b) frequent reference to the nature of science, implicitly by the teacher, (c) frequent use of anecdotes to promote instruction and establish rapport, and (d) a pleasant, supportive environment.

**Dennis** (104) investigated the effectiveness of advance organizers and repetition at the high school level with respect to measurement of lower level and higher level cognitive skills. Four groups of tenth-grade students enrolled in advanced biology classes were utilized. Four treatments varied in: (a) presence or absence of advance organizer, and (b) repetition of a slide-tape presentation. Results showed no significant differences in gains from pretest to posttest.

**Fields** (124, 125) conducted an aptitude-treatment-interaction study of lecture vs lecture-plus-classroom-activity in high school biology. Aptitude was measured in terms of Piagetian tasks and field independence/dependence. Achievement was measured using a criterion referenced test of eight biology concepts. Results showed that (a) while both aptitude variables affected achievement, cognitive ability had a stronger influence and (b) the treatments differed little in the aptitude-treatment-interaction. Highest achievement was found among those students who were field independent and of higher cognitive ability.

**Burns and Okey** (62) compared the effects of conventional lectures and instruction using analogies with four classes of high school biology students. Students were pretested to determine their cognitive ability level and comprehension of analogies. Results indicated that all students benefitted from instruction using analogies. Students with greater comprehension of analogies and those with higher cognitive ability showed greater benefit from use of analogies.

**Ableson** (1) studied the effects of selected biofeedback techniques on reading comprehension in a high school chemistry class. Results showed that relaxation was not associated with improved reading comprehension.

**Azencot and Blum** (13) examined the effects of a story-based strategy to enhance lower secondary students' ability and motivation to read bio-technical texts. Story-type chapters containing dialogues were presented to students before they read the text. This treatment was found to increase students' objective understanding of terms and enhanced their subjective assessment of the ease and attractiveness of the bio-technical text.

Fortner (132) compared the effectiveness of classroom TV documentary film presentation on grade nine students' knowledge and attitudes about marine mammals. Using a quasi-experimental design, two groups of students were instructed using: (1) a teacher presentation of the contents of a Cousteau TV documentary, or (2) the video documentary. A control group received no instruction. All three groups were pretested and posttested prior to TV airing of the documentary. A delayed posttest was administered to all students two weeks after public broadcast. Results showed that comparable presentations in either medium can result in increased, retainable knowledge. Attitude changes were apparent with the TV group but not with those who received the teacher presentations. However, significant attitudinal differences did not persist.

Mhone (255) investigated the use of the cognitive-graphic organizer as a facilitative factor in the understanding and retention of seventh-grade science content.

Two studies showed that remedial teaching resulted in improved achievement. Two other studies showed that analogies constitute a useful pedagogical tool for helping students improve comprehension of science content as reflected in improved achievement. Shapiro's finding that analogies require less cognitive capacity, thereby constituting more efficient mental processing, enriches our understanding of this pedagogical strategy.

A finding by Lederman and Druger gives rise to a concern. They showed that certain pedagogical techniques increased students' conformance to their teachers' viewpoints. The concern is with the application of these results. Should science teachers be attempting to have students conform to their viewpoints or should they be attempting to nurture critical, analytical thought? Without intending criticism of this study, science educators need to be cognizant of and act upon the philosophical issues embedded in these results. Moreover, we must assure that the purposes of science education are adequately deliberated so that practicing teachers and those who prepare them reach an informed, yet independent, decision regarding the purposes of science instruction.

## Elementary Level Studies

**Slade** (348) studied the effects of reading-study strategies on reading comprehension and attitude toward science among sixth-grade students. Results favored teacher-directed reading-study strategies over independent reading study strategies in nurturing positive attitudes toward science. However, no differences in achievement were attributable to the different treatments.

**O'Connell** (275) investigated the influence of content organization and relevant prior knowledge on the cognitive structure and achievement of sixth-grade science students. Two pre-treatments were used: an Ausebelian advance organizer and a content overview followed by instruction in basic geology content. The results showed that the content overview treatment was statistically more effective than the expository advance organizer treatment when both were assessed by an achievement test. Both treatments were equally effective on the Bloom's Level I questions but the content overview treatment was statistically more effective on the Bloom's level II questions. No interactive effects were found between treatment and prior knowledge of the content or knowledge of the concepts included in the pretreatment.

**Hamrick** (155) conducted a study to determine whether students experiencing resequenced and overtly interrelated general science content with respect to clarifying content structure would exhibit higher science achievement, more positive attitudes toward science, and greater interest in science when compared to a control group of students experiencing the same content not resequenced. Data were collected from 203 sixth-grade science students after one year by way of a standardized achievement test, and two Likert-type instruments which measured the two affective variables. The results indicated that students experiencing resequenced general science content demonstrated significantly greater science achievement, greater interest in science and more positive attitudes toward science than did peers receiving content in the standard form. Also, significant correlations were found between attitudes toward science and interest in science within both levels of treatment. A major conclusion was that establishing content structure through resequencing chapters for general science learners has positive effects on both cognitive and affective aspects of learner performance. Additionally, attitudes toward science and interest in science were highly related and interdependent.

Johnson et al. (196) studied the effects of cooperative and individual learning situations, using single-gender and mixed-gender groups, on relationships between male and female and handicapped and non-handicapped students in grades five and six. Results indicated that cooperative learning situations, compared to individualistic ones, promoted more positive cross-sex and cross-handicap relationships. It was also found that males achieved higher and had more positive attitudes toward science than did females.

Okebukola (276) studied the relative effectiveness of cooperative and competitive interaction techniques with Nigerian eighth-grade science students. Five different treatment plans were used which varied in the degree of cooperation and competition among students as they studied two units in their standard curriculum. Results showed that combinations of cooperation and competition were found to be the best methods of instruction. Procedural demands on teachers using these methods were relatively easy.

Johnson et al. (195) studied the effects of controversy and concurrence seeking and participation in age-homogeneous and age-heterogeneous cooperative learning groups. Comparisons were made on achievement, achievement motivation, perspective-taking accuracy, and interpersonal attraction. In addition, the interaction among 112 fourth-, fifth-, and sixth-graders within the cooperative learning groups was observed. Results showed that controversy promoted higher achievement, greater achievement motivation, and a more accurate perspective than did concurrence seeking. Also multi-age groups demonstrated greater achievement motivation than single age groups.

Foster and Penick (133) investigated whether cooperative small groups would stimulate creativity more than individualized learning environments among fifth- and sixth-grade students. Results indicated that after a two-week treatment period, students working in small groups scored higher in a posttest of creativity than did those who worked individually.

With only seven studies at the elementary level, variously addressing the influences of instructional treatment on student achievement, it is difficult to formulate conclusions. Hamrick's study provided a very promising lead for future research. Her finding that resequencing content for more effective instruction resulted in improved achievement, interest, and attitudes is a very positive result. More research on this topic is needed to reconfirm these findings and to explore the effectiveness of different content structures.

Three studies examined various questions related to cooperation and competition in learning. While methodologies varied among these studies, results were mixed. Perhaps Okebukola's finding, that a combination of competition and cooperation was effective with students and easy for teachers, presents a promising avenue for future research. Finally, Johnson's finding that introduction of controversy resulted in higher achievement than did seeking concurrence has significant implications for science educators as we continue efforts to incorporate technological and societal issues within the framework of science instruction. However, paralleling Okebukola's finding, one could ask if the combination of controversy and concurrence may not be more productive of the kinds of learning outcomes essential for effective citizenship in our society.

## Science Instruction for Gifted Students

Five studies were directed primarily toward research on programs for gifted students.

Subotnik (368) studied the problem-finding behavior of 146 Westinghouse Science Talent Search winners. Using results from a questionnaire, she found that: (1) students received more help in problem identification from people outside of school than from teachers; and (2) females and students who chose live science projects demonstrated greater concern for the social impact of research than was the case for other students.

Betkouski and McDonald (30) compared problem-solving behavior of high school students identified as potential National Merit Scholars and those in level one biology. Results showed that academically talented students scored higher on problem-solving tasks, were more verbal and more methodical in processing information, and were more likely to relate questions to their own experiences. Average students often looked for a literal match between the question and the text and were more likely to base answers on "naive theories" even when they were in conflict with text material.

Muller (261, 262) evaluated a junior high school science and mathematics program that was used with gifted seventh-grade students who were given accelerated and enriched instruction in mathematics and enriched instruction in science and computer science. Tests of achievement in all three subjects were prepared from objectives for all three courses. An attitude scale also was constructed. Significant increases in achievement were found for science, mathematics, and computer science. A subtest analysis of the science test revealed a significant increase in biology achievement but no increased chemistry achievement. The mean pretest and posttest scores on the attitude scale were positive but were not significantly different. Parents of students involved in the program were given a questionnaire asking them to rate their child's performance on 14 school-related behaviors. For all items, the mean parent' rating of child performance was in the positive range. The results are discussed according to achievement, attitudes, and opinions for the mathematics, science, and computer science courses, and in regard to general program issues. Recommendations include special attention to the student selection procedure and to the supervision of teacher activities.

Piburn and Enyeart (295) contrasted the reasoning ability of 217 gifted students in grades 4-8 with 91 mainstreamed students in grades 7-10, using a battery of Piagetian measures, the Proportional Logic Test and a variation of the Fair-Card Hypothesis Testing Task. Results observed that gifted students were advanced over the mainstreamed students in basic reasoning skills by 2-3 grade levels. They suggest that reasoning tasks such as those used in the study should be included as criteria in selecting students for accelerated/enriched programs.

Olson (280) studied the use of factor analytic cognitive ability tests to match cognitive styles of gifted students to instructional methodologies of exposition and inquiry. Three independent variables were examined: (1) on-topic student-student dialogue, (2) agreement and praise student-student dialogue, (3) propositional reasoning student-student dialogue. The intact gifted middle school population of Seattle Country Day School was given a battery of cognitive ability tests allowing the identification of two attention-focus categories referred to as socially-oriented students and puzzle-oriented students. Dialogue was tape recorded from groups of four students composed in the following three ways. (1) Four socially-oriented students, (2) two socially-oriented and two puzzle-oriented students, (3) four puzzle-oriented students. Results showed that more on-topic words and more propositional reasoning consistently occurred during inquiry lessons. Results also indicated that dialogue behavior is affected by grouping peers according to cognitive ability. Puzzle-oriented students used propositional reasoning more than socially-oriented students. The amount of propositional reasoning for socially oriented students increased when they were grouped with puzzle oriented students.

Subotnik'a study of Westinghouse Science Talent Search Winners focused on a very interesting question -- problem finding behavior, with a very interesting group. This type of research, with very able students can improve our understanding of the characteristics and promise of future leaders in science. It also can help us understand the influences which school-based programs have (or fail to have) on them.

Work by Betkouski and McDonald and others reported here also helps to illuminate the characteristics of very bright students and differences between them and other students. Knowledge of these characteristics will be helpful in planning instruction for both gifted students and students of average ability. Over the years, science educators and others who have been studying gifted students have amassed considerable data on their characteristics and their differences when contrasted with other students. Perhaps it is time to review these results and to make serious recommendations for practice and further research in this very interesting area.

### Non-formal Science Education

Our intuition and experience tell us that non-formal science education makes very important contributions to the scientific literacy of the members of our society. Television programs and visits to museums, zoos, nature centers, and parks augment school based science instruction in ways that many educators value. However, members of the science education community, like their counter-parts in non-formal education, have relatively little systematic knowledge to support our intuition.

Nine studies of non-formal science education were reported. Three of these studies focus on adults. One author examined the influence of experiences at a zoo on both children and their parents and five studies address non-formal programs directed toward school-age youth.

Wakely (407) conducted a historical study of adult education about atomic energy, 1945-1948, as a case study in science for society. Results of this study showed that awareness of atomic energy was nearly universal among adults in the U.S. by 1947, yet deeper understanding and public concern for its international implications were difficult to achieve. Success depended on the devotion and abilities of individuals in their own communities. The experience of these educators exemplify the necessity of grass-roots involvement, if such educational programs for adult citizens are to be effective education for change in an increasingly technological world.

Television provides numerous science and technology-based programs each week to large audiences. However, their educational influence on viewers is relatively unknown to many science educators. Kane (205) investigated the influence of a television program entitled Gulf of Maine: A Sea Beside the Sea on the attitudes of 249 adult volunteers from coastal and inland communities in Maine. A 30 element semantic differential test was used to assess attitudes before and after viewing the program. Data showed a general improvement in attitudes following the program. Females were more likely to learn new information than males, while frequencies showed that 94.7 percent of respondents enjoyed the program, 96.7 percent thought it easily understood, 92.3 percent thought it fair, 75.5 percent learned new information, and 83.6 percent wanted more similar programs. Factor analysis by two data sets revealed the subjects exhibited the most favorable response to two factors:

environmental concern and the rugged power of the Gulf of Maine water. A graphical interpretation of data showed basically neutral or positive involvement throughout the study with modest shifts in involvement. Data also showed that short scenes and narrations of marine concepts in the video program appeared to be the most effective way to influence and maintain positive marine attitudes among the viewers. This is a very interesting study and more research on non-formal learning by adults and youth through television should be encouraged.

Brody (56) applied concept mapping, Vee diagrams and individual interviews to the design of marine trades adult extension curricula and organizational feedback systems. This study was directed toward the question, "How does a theory of educating come to bear on extension education?" The researchers investigated how Sea Grant extension can design events to secure cooperation among people to achieve common goals and feedback information to guide future programming. An exemplar case of functional Program Advisory Committee (PAC) was analyzed to determine those criteria PAC members should exhibit. Mapping techniques were used to trace lines of influence and communication in the extension program. In the broader social context, the Lake Ontario lake trout creel limit controversy was Vee analyzed to indicate the role of policy, evaluation, management and science in determining mutually agreed upon natural resource decisions. This analysis, together with interviews of Long Island captains, forms the basis for the design of extension events to help resolve natural resource conflicts. This research indicates that a theory of educating forms an integrated and comprehensive conceptual framework for the Sea Grant Marine Advisory Service. The new educational techniques described provide agents with tools that better enable them to design and evaluate extension education programs.

Jonas (201) reported on an evaluation of the Lockheed Technological Emphasis Camp, which was a pilot program designed to expose high school juniors and seniors to aerospace technology. The program (1) emphasized the value of mathematics, science, and technological education through application in the aerospace industry; (2) provided stimulating experiences that rewarded high achievement, and helped students in personal growth and career direction; (3) provided a means for participants to share their experiences through planned presentations at their home schools; and (4) established new linkages to support public, education, parents, and others in the pursuit of excellence in mathematics, writing, and reading.

Eylon et al. (119) studied the use of extra-curricular science activities as a supplement to school-based science instruction. They examined ability levels, attitudes, expectations, and affective outcomes of 147 junior high students who voluntarily enrolled in extra-curricular science activities at Weizmann Institute of Science (Israel). Results indicate that for high ability students there was a need for theoretical and experimental independent study which can be found in extra-curricular science programs.

Ostlund et al. (288) conducted a naturalistic study of a project conducted at the Minnesota Zoological Gardens, designed to increase scientific literacy of two age groups by simultaneously exposing middle school children and their parents to short science courses. Findings show that parents and children made significant gains in learning and that they found the experience enjoyable and valuable. Middle school students' attitudes toward their parents and the course were significantly higher if the children perceived a highly cooperative learning environment with their parents. Also, parents who scored in the medium or high range on the pretest had significantly more interactions with their children about course tasks than those who scored low on the posttest.

Friend et al. (139) studied the effects of Newsday's "Science Education Series Program" on selected ninth-grade students' comprehension of science reading material. Two treatments were compared: (a) the Newsday Program, and (b) teaching the same content without the Newsday articles. For students with standardized reading and mathematics achievement scores at least two years above grade level, no differences were found between the effects of the two treatments in improving reading comprehension. For students whose reading and math achievement was at grade level, however, students using the Newsday Program found improved reading comprehension.

Pomerantz (299) studied the influence of "Ranger Rick" magazine on third, fourth, and fifth grade children's perceptions of natural resource issues. A pretest/posttest questionnaire was administered in class to a sample of fifth graders. After the three-month treatment period, the treatment group increased its knowledge of animals, plants, and ecological principles. There were no significant differences between treatment and control subjects in conservation attitudes, anthropomorphic attitudes, or conservation and wildlife-related activities. Children rated magazines as their number one source of information about wildlife and the environment. Books, school, and T.V. ranked second, third, and fourth, respectively. A second pretest/posttest experiment of 417 third, fourth and fifth graders compared the popular magazine style used in "Ranger Rick" with a classical science textbook format. Children learned from both sources. However, the magazine had a greater impact when it used a detailed presentation of scientific information about plankton that was accompanied by a color photo display. The storybook style, which presented information on soil conservation, was not as effective in increasing children's environmental knowledge. A mail questionnaire was sent to a nationwide sample of 12,000 "Ranger Rick" subscribers. The responses of more than 3000 respondents showed that the majority of children who read "Ranger Rick" were males, were between 7 to 12 years of age, and had been receiving "Ranger Rick" from 2 to 3 years. They liked to read "Ranger Rick" to learn about animals and conservation and because it was fun to read. Their favorite parts of the magazines were the animal stories, adventure stories and pictures. The majority liked stories of animals that are different and strange, and were not offended by stories about predation. Three-fourths of the respondents said "Ranger Rick" magazine helped them with their schoolwork.

McManus (251) conducted a survey of how worksheets are used by groups of children in the British Museum and offered some guidelines for organizing worksheets for use with out-of-school activities in science.

These nine studies touched upon extension education programs, television, magazines, and zoos which are part oft he non-formal science education network that has a little-known impact on the scientific literacy of our population. These results suggest that non-formal educational experiences have a strong influence on attitudes and, when effectively organized, increase the understanding of included concepts by audiences. Investigations of the effects of non-formal science education, in its varied forms, appears to be a promising area for science educators. However, research questions and approaches may need to be adapted to this different educational milieu.

## Influence of Instruction on Cognitive Skills

Seventeen studies were included under this heading. Five of these studies examined the influence of academic instruction on students' cognitive abilities. Four other studies examined the effectiveness of instruction designed specifically to improve students' cognitive skills. Eight studies concerned spatial visualization skills of students and efforts to improve them.

### Influence of Academic Instruction on Cognitive Skills

**Musser** (263) compared the effects of high school chemistry and non-chemistry experiences on students' operative comprehension as measured by the Raven Content Comprehension Test. Results after one semester of chemistry showed significant effects for treatment, gender, and school on the compensatory reasoning subscale and for treatment and grade level on the correlational reasoning subscale.

**Kopp** (216) tested an information theoretic model in quantitating the quality of prose cognition sequences evoked by 175 college biology students. They read a passage on vaccination and then completed an immediate prose recall. One month later, the students completed a prose recall and a science concepts objective test. The results of this investigation provide evidence that humans differentially process cognitions for semantic and syntactic structural properties. Immediate and delayed verbal cognitions differ in information processed as a function of language facility, objective test performance, students' gender, and mental maturity.

**Petrushka** (294) studied the effect of content familiarity on students'ability to use syllogistic reasoning with tasks involving logical connectives and inclusive disjunction. The influence of linguistic content on inference patterns also was examined. This study was prompted by Piaget's own questioning of the appropriateness of the hypothetico-mathematical model used in his studies of children's reasoning. It was found that familiar content greatly increases success with these two formal operators, with more difficult inference patterns showing the most improvement. Additionally, it was of interest to determine whether logical skills which led to success with familiar-content tasks were transferable to other contexts, and further generalizable to symbolic content. The effect of practice on logical competence was also investigated. The results showed that these skills are transferable to other contexts, and with a minimum of practice become generalizable to the hypothetico-mathematical situation. By dividing the syllogistic tasks into two sub-tasks and testing each separately, it was found that familiar content exercises a positive influence on proficiency with the encoding component of the task for both logical connectives. Also, familiar content enhances competence with the logical component of the inclusive disjunction operator, but not the implication operator.

Jesunathadas and Saunders (193) studied the generalizability of ninth-grade students' proportional reasoning abilities across subject matter domains that included both familiar and unfamiliar task content. Students completed a 22-item test which included 12 word problems requiring proportional reasoning. Items were constructed at three levels of difficulty and used "familiar naturalistic" content and "unfamiliar science textbook" content. Results showed that students had greater success at solving problems with familiar than unfamiliar task content, especially for problems involving simple ratios (but not problems involving difficult ratios).

Kwon and Mayer (220) reported on the development and use of a technique to study the "momentum effect" in studies of learning. The "momentum effect" is the post-intervention increase in learning of subject matter. In their study, the subject focus was on eighth-grade students' learning of plate tectonics. Results indicated that the duration of the momentum effect was related to the level of student understanding tested and the cognitive level of learners.

Four of the five studies reported above pointed to the positive relation between content familiarity and improved information processing and logical reasoning. This research supports our intuitions that increased background knowledge is important in subsequent learning. However, the studies do not clarify a fundamental issue about causal relationships.

### Direct Intervention Upon Cognitive Skills

In an experimental study, Crow and Piper (97) evaluated the effectiveness of instructional aids designed to improve test scores of field-dependent community college students enrolled in an introductory geology course. Thirty-six students classified as field-dependent, based on the Witkin Embedded Figures Test, were assigned to a treatment and a control group. Both groups were given identical instruction in geology; treatment group members also received instructional aids designed to enhance ability to discern structural features in a natural formation. At the end of one semester of instruction, field-dependent students in the treatment group scored significantly higher on an achievement test than did field-dependent students in the control group. This finding indicates that field-dependent students' scores on tests can be improved significantly with a few additional instructional aids directed to needed situations.

Collings (89) studied the relationship between training in the cognitive restructuring aspect of field-independence and the development of formal operational thought among 11- and 12-year olds. Instructional treatment included computer-based activities. Cognitive restructuring was found to be associated with increased formal operational thought.

Bodner and McMillen (47) studied an approach to cognitive restructuring of problems presented to college-level chemistry students as an essential initial step in problem solving. They provided strategies (a) to aid students in disembedding information from written statements of problems, and (b) in restructuring problems so they could be activated with the popular "road map" approach to problem solving. Initial results of this work have shown that students' ability to disembed and restructure tasks in the spatial domain is correlated with ability to solve simple stoichiometry problems.

Crow and Haws (99) studied the effectiveness of integrating logical thinking skills within an undergraduate geology course for non-science majors. Results comparing treatment and control groups showed that both logical thinking and achievement in understanding of course content were enhanced by this treatment.

These four studies suggest that direct intervention in logical processes can benefit students' reasoning ability and science achievement. This appears to be a promising area for additional research. However, future work should be based on a reflective analysis of past studies and formulation of an appropriate conceptual framework to guide research. This is an area where science educators could benefit from cooperation with cognitive psychologists and philosophers of science.

## Spatial Visualization

Spatial visualization appears to be an essential ability for comprehending certain scientific concepts, including those related to molecular and anatomical studies. Eight studies were reported in this category. The first five reviewed below are non-interventional studies which improve our understanding of spatial visualization among youth, including three studies that explored the influence of spatial abilities on achievement in science classes. The last three studies in this section were interventions to alter students' spatial visualization capabilities.

Seddon et al. (336) determined the factor structure of tasks which require students to visualize how diagrams should be drawn to represent effects of rotating three-dimensional structures about the three Cartesian axes. Results obtained from 149 English and 231 Singaporian high school students show that visualization about X-, Y-, and Z-axes are factorially distinct.

Russell-Gebbett (327) studied abilities of 11-15 year old students in interpreting three-dimensional structures in a biology context including sectional views of eggs, cells, stems, and fish. Results showed that two skills are needed for success: abstracting sectional shapes and appreciating spatial relationships of internal parts.

Cohen (88) conducted a cross-cultural study of the development of spatial conceptual abilities among sixth- and tenth-grade children living on the Navajo reservation and those in schools in Mesa, Arizona. A battery of 10 Piagetian-type tasks were administered individually. Results supported the contention that there were no substantial time delays or advances in development of selected spatial abilities of Navajo students compared to parallel non-Indian students. Therefore, modifying instruction in science to match supposed differences in spatial structures of students appears to be unwarranted.

In a replication of an earlier study by Bodner and McMillan, Carter and her co-workers (71) studied the effects of students' spatial abilities on achievement in college-level chemistry. Among the findings are those which showed that students with high spatial-ability scores outperformed students with low spatial-ability scores and that spatial ability is correlated with success in chemistry.

Pribyl and Bodner (306) studied the influence of students' spatial ability on achievement in organic chemistry. It was learned that students with low spatial ability scored significantly lower than peers with high spatial ability in course examinations. Also, students with high spatial ability made more use of drawings than did other students in answering test question. Also, students who drew pictures as an aid in answering questions scored higher on examinations than those who did not draw pictures, regardless of spatial ability.

Lord (236) studied the influence of instruction on the visuo-spatial aptitude of 84 undergraduate biology students. Treatment extended for 30 minutes per week over one semester. Employing an experimental design, including both experimental and control groups, pretest and posttests were administered using the ETS Kit of Factor Referenced Cognitive Test and The Planes of Reference Test. Results showed that the experimental group improved in spatial visualization and spatial orientation.

Broughton (58) studied the effect of using photographs, photographic techniques, and three-dimensional models on the ability of ninth-grade physical science students to interpret selected abstract concepts. Four treatment groups differed in their use of visual and concrete models. Results showed improved achievement on the Test of Inquiry Skills resulting from increasing use of visual and concrete materials during instruction.

Seddon and Shubber (337) studied the effect of six instructional programs, each dealing with a different aspect of spatial tasks related to diagrams of three-dimensional objects, with 13-17 year olds in Bahrain. All brought about significant degree of learning to students in all age groups.

Three studies (Carter, Pribyl and Bodner, and Lord) demonstrated relationships between spatial visualization ability and achievement. The last three studies presented above showed that direct intervention regarding spatial visualization can affect students' spatial visualization abilities and their achievement. Putting these two sets of findings together, it would appear that science programs should give specific attention to instructing students in spatial visualization as a way of enhancing comprehension of scientific principles. At a simple level, encouraging students to use diagrams as analytical tools, as suggested in Pribyl and Bodner's study, would be one easy step that teachers could use that appears to influence comprehension and achievement.

## Research on Laboratory Work in Science Instruction

Laboratory work is an accepted part of science instruction. Given its important place in the education of youth, it is surprising that we know so little about its functioning and effects. Sixteen studies reviewed here provide a small addition to needed research in this component of science instruction.

These studies focus mainly on laboratory work at the secondary school level. Therefore, unlike other topics in this research summary, the secondary school articles are summarized first. Four articles focus on tertiary laboratory work are at the end of this section.

Hounshell (181) used a questionnaire to study secondary science teachers' views on laboratory work. Areas explored included actual and ideal time allocated for teaching methods (demonstrations, discussion/oral reports, in-class paper work, laboratory, or lecture), whether students change as a result of laboratory work, major impediments to laboratory work, effectiveness of laboratory work compared to demonstrations on the same topic, time per week devoted to laboratory work, money spent per pupil on laboratory supplies, equipment and materials, and how much money, per pupil, is reasonable for these items. Questionnaires were mailed to 358 science teachers in all regions of North Carolina. Among the findings reported are those indicating that only 40.7 percent feel that their students "learn a lot" in the laboratory and that 83 percent use laboratories less than 30 percent of the time (45 minutes or less per week).

Bryce and Robertson (59) reviewed studies assessing laboratory work in secondary schools in the U.K. Areas encompassed by this review included students' actions in laboratory, assessment of students' laboratory skills, methodological issues, and reasons for failure of some approaches to assessment of laboratory work.

Okebukola (277) studied behaviors of 600 high school students in high school biology laboratory settings. Observational data, laboratory skills, and attitudes were measured using the Science Laboratory Interaction Categories System, the Biology Practical Test, and the Attitude Toward Laboratory Work Scale. Results showed that transmitting information, listening, and non-lesson-related behaviors exhibited low correlations with practical skills and attitude measures. Correlations between manipulating apparatus and observation with practical skills were strong. Multiple correlation analysis revealed that behaviors of students in laboratories accounted for a large percentage of the variance in scores on manipulative skills. Planning and design of experimental work, attitude toward laboratory work, and laboratory skills were found to be important factors in student performance.

In another study, Okebukola (276, 278) examined the effectiveness of cooperative, competitive, and individualistic interaction patterns in promoting acquisition of science process skills during biology laboratory activities. Results (from 720 secondary students--352 girls and 368 boys) showed that competitive interaction was superior to cooperative and individualistic interaction patterns in promoting the development of process/laboratory skills.

Cavana and Leonard (73) studied the effects of providing high school biology students with opportunities of using their own discretion in carrying out laboratory activities. Laboratory activities were divided into two components: described and discretionary. Students were then encouraged to use their own judgment in approaching the latter tasks. When compared with students taught under a standard BSCS laboratory approach, students in the discretionary approach: (a) scored higher in a test of laboratory concepts, (b) produced higher quality written reports of laboratory work, and (c) were more capable of exercising independent judgment for a greater amount of time. Teachers spent about twice as much time preparing for these labs as they did in preparation for standard laboratories and they were reluctant to accord students more discretion.

Fields (125) compared the effects of augmenting verbal instruction in high school biology with laboratory activities on students of differing cognitive capability. When tested using a cognitive developmental test, 100 high school biology students were categorized as 54 percent concrete operational, 35 percent transitional, and 11 percent formal operational. Independent variables were the two treatments (verbal and activity-augmented instruction). Achievement on concept tests constituted the dependent variable. Results indicated that the two treatments did not differ in their effectiveness in promoting mastery of formal biology concepts across cognitive ability levels. A strong relationship was found between mastery and cognitive ability levels--i.e., high cognitive ability level favored mastery. It appears that conventional use of typical biology laboratory activities does little to foster the achievement of abstract concepts, as measured by paper-and-pencil exams.

Payne (293) studied the effects of an introductory, laboratory-based microbiology course on 23 selected high school students. The course was subjected to formative evaluation as it was taught. Students were given both pretests and posttests. Results showed that selected high school students can comprehend the content of microbiology and manipulate the tools needed to study microorganisms.

Renner et al. (317) interviewed secondary school students to determine beliefs about the physics laboratory. Results indicated preference for laboratory activities because such exercises help students remember, are less confusing, and more concrete. Use of the laboratory as an introduction to a concept, followed by discussion, was a key component to this learning cycle approach.

Ivins (189) compared inductive and deductive approaches to instructional sequencing in seventh-grade earth science classes. The study specifically examined whether 103 seventh-grade earth science students introduced to science concepts through laboratory exercises, followed by textbook readings and classroom discussions, learn and retain these concepts better than students who have the concepts introduced through textbook readings or teacher lectures followed by verification laboratories, and if these students also have a stronger preference for science than the latter group of students. Results indicated that students experienced greater achievement and retention when directed discovery learning laboratories were used to introduce new concepts when compared to the same laboratory activities used as verification laboratories. The difference in preference for science between experimental and control groups was not significant.

Brody (57) studied the effect of first-hand experience on a floating laboratory on 20 eighth-grade students' values and comprehension. Modified clinical interviews that incorporated concept mapping and concept propositional analysis were administered in a pre- and post-trip manner. Results indicated that students interviewed exhibited an increase in marine science concepts and values toward coastal zone resources.

Dombrowski and Hagelberg (106) studied the effects of a unit of instruction on laboratory safety on high school students' safety knowledge and behavior. Nineteen introductory biology and chemistry classes were included in the study. Safety knowledge was tested before and after instruction using a locally developed 23-item test. Following the posttest, laboratory behavior was assessed using a checklist. Results showed that knowledge level increased and frequency of unsafe behavior decreased following instruction.

Chaney (78) formulated an annotated bibliography of literature dealing with hazardous chemicals used in chemistry laboratories. The study investigated three areas: (1) chemicals used in the academic laboratory which pose a health hazard, (2) ways of reducing toxicity in the laboratory (addressing the apparent lack of teacher training which contributes to the cause) and (3) state and federal regulations and resource materials for the proper handling and disposal of hazardous chemicals. Findings indicate the need for teachers to be informed of the chemicals which are potential health hazards. In addition, educating laboratory instructors to the hazards of certain chemicals is the initial approach to reducing the dangers of chronic poisons in the classroom. Chaney concludes her work with recommendations for: (a) removal of carcinogenic chemicals from classrooms and storage areas, (b) having laboratory instructors properly trained in laboratory safety, and (c) formulating and using a predetermined waste disposal program before an experiment is performed.

Beasley (23) studied the effects of physical practice, mental practice, and their combination in improving laboratory skills among freshman chemistry students. Although no significant differences were found between treatments, there were significant differences when each was compared to the control sections. Mental practice appears to offer an efficient method for reinforcement without expenditures of resources.

Gabb (141) compared two uses of video in evaluating laboratory programs in tertiary level physics and zoology courses. One method involved interaction analysis of student behavior while the second was based on stimulated recall techniques. One student in each of 13 laboratory classes was studied to compare the methods. To determine the relative utility of the information produced by the two methods (including usefulness of the information, preference for one or the other method, and limitations of information provided), nine staff members were given a brief introduction to the project and summaries for the two methods. All nine teachers were interviewed and indicated that the information was useful in developing laboratory programs. In addition, they expressed a preference for the information generated by the second method (stimulated recall).

Spickler (357) compared the effects of laboratory instruction designed to enhance physical intuition with standard laboratory instruction with a group of 59 prospective elementary education majors assigned to treatment and control groups. Posttest explored students acquisition of factual recall, comprehension, and application following Bloom's Taxonomy. Results showed that laboratory instruction of a sensory feeling nature resulted in improved reasoning at the comprehensive level.

Lawrenz (223) studied aptitude-treatment effects of laboratory grouping for students of differing reasoning ability. Prospective elementary teachers were grouped acccording to high, middle, and low reasoning ability. Three treatment groups were then established: homogeneous laboratory groupings, heterogeneous laboratory groupings, and self choice of laboratory grouping. Results showed: (a) no aptitude-treatment interaction for achievement or gain in formal reasoning ability, (b) grouping students of similar cognitive ability for laboratory work was more effective than the other alternatives in terms of achievement, (c) students of different reasoning ability showed differential gains over the semester, with students in the low group showing greatest gains.

These studies imply that laboratory work has an unrealized potential in science instruction. Hounshell's finding that 83 percent of teachers surveyed had less than 45 minutes of laboratory instruction per week for their students suggests that laboratory work may not be a central part of instruction in science at the secondary school level. Moreover, the questions underlying many of the studies reported here also imply uncertainty about the instructional role of laboratory work at the secondary level. It appears that renewed efforts are needed to assess the potential benefits and place of laboratory work in the secondary school science program. The same may also be said of laboratory work at the tertiary level.

An indepth review of pertinent research literature would be a good starting point, followed by a conference or Delphi study designed to formulate a sound research agenda on the laboratory in teaching secondary (or tertiary) science. As a profession, we need to reaffirm or redefine the purposes of laboratory work in science teaching and then conduct the needed research to help formulate and implement policies and programs to achieve these purposes.

## Microcomputer Applications in Science Education

Microcomputers have been part of the educational scene for most of this decade. They are used in many schools, but we know relatively little about their influence on students' learning or about how they are used in science teaching.

Twenty-seven studies of computer applications in science were reported. Five of these address broad questions about computers as an adjunct to science teaching while the other 22 studies address specific questions regarding students' learning which results from computer-based instruction. The latter categories range from university to middle school and include studies in each of the science disciplines and in teacher education.

### Broad Questions About Computers and Teaching

Lehman (231) conducted a survey of computer use in 193 high schools and found that few science teachers used computers regularly in classrooms. This report also examined possible reasons for limited use of computers by secondary science teachers.

Larsen (222) studied university faculty attitudes toward computer-based education. Faculty from various disciplines were interviewed to determine their attitudes toward computer-based education. Experience with computer grading of tests and use of objective tests, coupled with the fact that two-thirds of the faculty members had some experience with computer-based education, indicate a base of knowledge conducive to use of computer-based education.

The usefulness of computer in education is dependent largely on the quality of courseware. Many teachers and educational researchers are dissatisfied with the quality of software available for instruction. Sethna (339) developed and validated an instrument for evaluating microcomputer simulation software for high school physics. It addressed issues such as strengths and weaknesses of the courseware and evaluations of simulation programs by teachers and students. Results showed that: (1) the instrument does not aid teachers in predicting students' perceptions of simulation software, and (2) students were more critical than teachers in identifying strengths and weaknesses of simulation software.

Tinker (390) analyzed the match between opportunities created by computer technology and needs in school science and mathematics instruction. Information was gathered by: (1) obtaining descriptions of available software; (2) reviewing published software evaluations, grant-supported software development projects, and a broad selection of software; and (3) by consulting experts in the field, school personnel, and software developers. Topics included in the report were software development, availability, content coverage, evaluation, information dissemination, acquisition, and use in schools. The report also examined the potential of software to increase students' learning and achievement and to improve teaching productivity and decrease costs. Among the findings it was noted that: (a) although software development is expensive and risky, software production is high; (b) schools allocate inadequate resources for software acquisition; and (c) software can increase the range of science and mathematics topics successfully covered.

Ellis and Kuerbis (117) reported on the development and validation of essential computer literacy competencies for science teachers. A list of 24 competencies was prepared which include: computer awareness, microcomputers in science teaching, selection and evaluation of software, and resources for educational computing. Computer programming, the history of computing, and computers and society were not rated as essential competencies. The competencies will be used to develop: ( 1) a test for measuring the computer literacy of science teachers, and (2) a curriculum for training science teachers to use the computer.

Data from studies by Lehman, Larsen and Tinker suggest that computers are not being used extensively in science instruction. This conforms with practical experience. In most secondary schools, computers are used largely to teach computer programming or for business applications. In elementary schools, word processing and drill activities are common. However, cognitive applications to science instruction are, at best, only occasional in typical school practice. Availability of appropriate software in schools is part of the reason that science teachers have not incorporated computers into science instruction. Lack of equipment, time, and technical support for teachers also appear to be important factors.

It appears that these deficiencies should be addressed if computers are to become an integral component of science instruction. However, data are sketchy and added research will help us understand why science teachers are not using computers for instructional purposes and how obstacles to their use may be overcome.

## Studies of Students' Learning from Computer-based Instruction

For the readers' convenience, the twenty-two studies that follow are grouped by subject area and then in descending order of academic level.

Narthasilpa (266) investigated the effect of two approaches to microcomputer instruction on knowledge and attitudes of 24 science-education students. Treatments consisted of a teacher-guided approach and an independent-learning approach. The treatment period for each group was three weeks in length with four sessions held each week and each session lasting a total of 95 minutes. The results showed that there were no significant differences in the mean score between the treatments on either knowledge of computer programming or attitudes at the completion of treatment.

Stager-Snow (358) investigated analytical ability, logical reasoning, and attitude as predictors of success in an introductory course in computer science for non-computer science majors. Testing 134 college juniors and seniors showed limited utility of the Propositional Logic Test and gender as predictors of success. Scores on the Group Embedded Figures Test were not useful as a predictor.

Zitzewitz and Berger (431) applied mathematical learning models to student performance on microcomputer drill and practice routines in college-level chemistry. Fifty-four students were engaged in drill and practice for a duration of less than 90 minutes, typically, on one of four topics. From the study the authors concluded that: (a) learning from short drill and practice routines correspond linearly with time spent, (b) students learn at different rates and programs differ in rates at which they impart learning to students, and (c) microcomputers continue to be a useful tool in studying student learning in science.

Summerville (369) examined the relationship between computer-assisted instruction and achievement levels and learning rates of secondary school students in first-year chemistry. The topic which students were learning during the investigation was the gas laws. Both experimental and control groups were taught the pertinent subject matter in a conventional manner. The independent variable in the experiment was access to computers for practice and calculations. No statistically significant differences were found in gain scores between pretest and posttest or in learning rate for the two groups.

Wainwright (405, 406) studied the effectiveness of a computer-assisted instruction package during a high school chemistry unit on writing/naming chemical formulas and balancing equations. Students in the experimental group received drill, review, and reinforcement using the microcomputer while students in the control group used conventional paper-and-pencil worksheets for their lessons. Findings showed: (1) that the use of the microcomputer materials did not contribute to more effective learning (the control group's scores were significantly higher on an achievement test than the computer-assisted instruction group mean); (2) no significant interactions favoring either computer-assisted instruction or control activity for students of differing cognitive levels as measured by Lawson's Classroom Test of Formal Operations; (3) that females displayed attitudes toward computers that were nearly identical regardless of treatment; that males' attitudes were far more favorable toward computers in the computer-assisted instruction group; and (4) that females' attitudes toward chemistry were more favorable in the control group while males' attitudes toward chemistry were essentially the same for experimental and control groups.

Leonard (233) compared tertiary-level students' perceptions of conventional biology laboratories and those employing an interactive computer/videodisc system. Students responding to questionnaires indicated satisfaction with the new approach and were pleased with its time efficiency. The interactive computer/videodisc system was judged to be equivalent to conventional laboratory instruction in the areas of general interest, understanding of basic principles, help on examinations, and attitude toward science. Students also had a strong perception that the images on the videodisc "were not real." It is inferred that the videodisc/computer technology will not likely serve as a viable substitute to the " wet" laboratory experience, but that this medium may substantially enrich the spectrum of educational experiences in typical classroom settings.

Waugh (411) studied: (1) immediate and continuing benefits associated with using microcomputer-assisted testing with 42 secondary school biology students, (2) types of students benefitting from microcomputer-administered diagnostic testing, and (3) the feasibility of microcomputer-administered diagnostic testing. Students studying the BSCS Blue Version text were divided into two groups which differed only in the use of microcomputer-assisted diagnostic testing. Results showed that students reacted favorably to diagnostic testing administered via computers but that aptitude, achievement motivation, and long term achievement were not altered as a consequence of it. However, over the short term, some achievement gains were noted. Cost analysis is also provided.

Vockell and Rivers (403) studied the effects of computer-based simulations on high school biology students' problem-solving skills. Students in the treatment group received both guided instruction and discovery learning experiences using simulations, while a control group received no simulations. Student performance was compared on (1) subsequent unit pretests, (2) standardized tests of scientific thought processes, and (3) standardized tests of critical thinking. Results indicated that students using the simulations met the unit objectives at least as well as the students in the control group. In addition, students using the guided version of the simulations surpassed other students on the subsequent simulation pretests, on the tests of scientific thinking, and on the test of critical thinking. In most cases, students using the guided version of the simulations developed these generalized skills more effectively than students using an unguided version. These results suggest that computer-based simulations can help high school students substantially increase their problem solving abilities. However, to be most effective, it appears that simulations should be integrated into the curriculum and guidance should be provided to assist students in efficient use of simulations.

Stevens (363) compared interactive videodisc instruction with standard laboratory instruction in a college-level physics course. Criterion instruments were an investigator-constructed content pretest and posttest, the Schwirian Science Support Scale, forms A and B, subjects' laboratory Data Tables, and Computer Recorded Data Tables. Using analysis of covariance, no statistically significant difference was found in the performance of the two groups on the Physics Content Test. An analysis of variance on the laboratory data tables and the computer recorded data tables showed that the two groups separated and controlled variables in significantly different ways, which appeared to be an artifact of differences in responses to visual patterns and real equipment.

Wankel (409) conducted an experimental study to compare the use of a videodisc and the use of hands-on equipment on student achievement in the learning of specific physics concepts in an introductory university level physics laboratory when students study the physics of standing waves. Thirty-six students were pretested to determine cognitive style, cognitive level, prior physics experience, and comprehension of specific physics concepts and randomly assigned to either of two treatment groups. Posttesting measured mastery of standing wave concepts. It was found that the students using the videodisc and students using the hands-on equipment made similar advances on the posttest. Yet, based on students' comments and observations by the researcher, the videodisc appeared to be a stimulating, safe, quiet, mobile instruction tool.

Carnes (70) studied the effects of varying group size and the use of advance organizers on high school students' learning resulting from a microcomputer, tutorial physics program. Dependent variables were achievement, retention, and rate of learning. Of nine hypotheses tested, only group size showed a significant effect with groups of 3-4 students having significantly better rates of learning than students working alone.

Wiser and Martins (421) conducted a study of high school students' concepts of heat and temperature in which computers were used to provide an instructional intervention. A pretest, treatment, posttest model was employed. The computer was selected as the primary instructional device because of its capacity to interface with equipment for heat and temperature measurements, to process data rapidly, and its ability to transform data into visual displays of tables and graphs. Study results indicated that use of the computer as the teaching intervention appeared to have helped the students to distinguish between heat and temperature but not to understand the notion of specific heat.

Bly-Monnen (46) attempted to determine if there is an optimal combination of concrete activities and verbalization in the expository or discovery environment which brings about greatest immediate learning, greatest transfer, and greatest retention when science instruction is delivered via student-microcomputer interaction. One hundred twenty, fifth- and sixth- grade students were randomly assigned to one of eight microcomputer-delivered treatments. Students were tested immediately following instruction and again approximately three and a half weeks later. A multivariate analysis of variance with repeated measures revealed no significant differences for main effect or interaction effects.

Mokros (257) conducted a descriptive study of the impact of microcomputer-based laboratories on sixth-grade students' understanding and use of symbol systems such as graphs. Sixth-grade students received five microcomputer-based laboratory lessons on distance and velocity, where they were challenged to construct different kinds of graphs via their own movements and the movements of a toy cart. Results (based on classroom observations and a post-intervention quiz which required students to match graphs with written descriptions of these graphs) indicated that after experience with microcomputer-based laboratories, students could accurately match complex graphs of physical phenomena with written descriptions of these graphs. Children attained a mean accuracy level of 85 percent on the matching task. Observations corroborated these findings, and showed that students' understanding of graphs was resistant to counter-suggestion.

Thornton (389) described the use of microcomputer-based laboratories in the study of motion in sixth-grade and university physics classes. Preliminary observations indicated that the linking of concrete measurement of an actual physical system with the simultaneous production of the symbolic representation may be an effective way for students to learn to correctly interpret and produce graphs.

Barclay (18) also studied the use of microcomputer-based laboratories in analyzing and remedying students misconceptions in graphing. His study is included in the section of this report dealing with misconceptions research.

Dillashaw and Bell (105) studied the influence of teaching computer programming to students in middle grades. Students were pretested and posttested using the Test of Logical Thinking. Eighteen students received ten weeks of instruction in programming, while a comparison group receive no instruction. The results indicated no significant differences in level of logical thought at the .10 level of significance (F=2.52; p=.12), suggesting that instruction in computer programming does not significantly enhance growth in logical thinking skills.

Shaw (342) and Shaw and Okey (343) reported on investigations of the effects of computer simulation, laboratory work, a combination of laboratory work and computer simulation and conventional instruction on sixth- and seventh-grade students' achievement and attitudes. Topics covered during the 10 instructional sessions were: processes of observing, hypothesizing, testing, classifying and reading data. Results showed that no attitudinal differences among the four treatment groups but simulation, laboratory activities, and combinations of the two resulted in higher achievement than was attained from conventional instruction. Also, students at high and middle levels of logical reasoning ability demonstrated higher achievement than students in lower achievement.

Berlin and White (27) studied the use of computer simulations as an aid to students' transition from concrete manipulation of objects to abstract thinking with a stratified sample of 113 second- and fourth-grade boys and girls from different socio-cultural sites. Results suggested that concrete experiences and computer simulations have different effects on children of different ages, gender, and different socio-cultural background.

Choi (80) compared the effectiveness of two instructional methods: a simulated experiment using the attributes of the microcomputer and the other utilizing parallel instruction involving hands-on laboratory experiences in the teaching of the concept of volume displacement with middle school students. Students were randomly assigned to treatment and control groups and were pretested, and posttested at the conclusion of the treatment and 45 days later. It was found that computer-simulated experiences were as effective as hands-on laboratory experiences, and that males, having had hands-on laboratory experiences, performed better on the posttest than females having had the hands-on laboratory experiences, while there was no significant differences on performance when comparing males with females using the computer- simulated experiment in the learning of the displacement concept. This study also showed that there were no significant differences on the retention levels when the retention scores of the computer-simulated experiment groups were compared to those of the hands-on laboratory experience groups, whereas an ANOVA of the retention test scores revealed that males in both treatment conditions retained knowledge of volume displacement better than females. This study suggests that computer-simulated experiences could be used in place of hands-on laboratory experiences with an expectation of equal performance levels by students in approximately one-half the time required for the hands-on laboratory experiences when covering certain topics in scecondary school science.

McNemar (253) used microcomputer simulations of science activities to study the relationship between sequencing and nature of learning activities and concept development. Middle school science students were given instruction on using negative instances in a conjunctive letter string task. When given sequences of instances and asked to identify the critical features of the microcomputer simulation of science activities, students were able to use negative instances and to identify the two critical features of the microcomputer simulation of science activities. Additional interpretations examine the value of mixing positive and negative instances in concept learning in science.

Three studies (i.e., Leonard, Stevens, and Wankel) compared interactive videodisc approaches to instruction with conventional laboratory instruction. No achievement differences were found; however, some auxiliary findings should be noted. Stevens found that students differed in the manner in which they separated and controlled variables as a consequence of the visual/experiential stimuli presented by the two approaches. Leonard noted that students perceived the videodisc experiences as "not real." Both studies raise questions about the appropriateness of videodisc in helping children connect science learning with their real world of experience. Studies by science educators and psychologists are needed to increase our understanding of this fundamental matter.

Several studies showed that computer simulations and regular laboratory activities had relatively equivalent effects on students' achievement. However, Mokros and Thornton showed that computer-based instruction was useful and effective in teaching students to construct and interpret graphs. Thornton's study was especially interesting in its linking of measurement of a physical system and production of a symbolic representation. This appears to be a valuable technique which is worthy of further development and testing.

A finding of high potential importance was made by Carnes who observed that high school physics students working in groups of three or four with computers had higher learning rates than students working individually. If this finding applies to other contexts, it would have important implications for budgets, facilities utilization, and instructional organization.

Lastly, Wainwright found that paper-and-pencil drill and practice was superior to computer-based drill and practice in helping high school students learn chemical formulas and names. This raises questions about the utility of computers for one of its early applications. Researchers in this field may wish to review other studies to assess the pertinence of this result for future research and practice. As in this instance, computer applications to science instruction is a fertile field of inquiry.

## Curriculum

**A substantial amount of the reported research fits the broad category of curriculum studies. To organize this, the following sub-categories were used (the number of studies in each is shown in brackets):**

A. **Analysis of Curricular Content [10]**

B. **Curricular Objectives [2]**

C. **Teachers' Selection of Content [2]**

D. **Program Comparisons [6]**

E. **Curriculum Development [2]**

F. **Curriculum Implementation [5]**

G. **Textbooks [16]**

### Analysis of Curricular Content

**Studies in this category covered a diversity of topics ranging from analysis of specific curricular and developmental issues to questions of content determination.**

**Osborne and Wittrock (287) examined the implications for science education of the generative model of learning. Their analysis: (1) placed generative learning ideas in the context of other viewpoints of learning; (2) explicated key postulates of the generative learning model; and (3) examined implications of these theoretical ideas for teaching, learning, curriculum development, and research.**

**Norris (272) provided an interesting and very useful analysis of observation in science and science education from a philosophical perspective. He underscored the importance of observation in scientific research and pointed out that it can range from a relatively simple to a very complex activity. Analysis of instructional materials in science, however, showed that they typically portray the simple end of this spectrum. Norris saw this as unnecessary and undesirable and thus recommended that the image of scientific observation presented to students should be changed to more accurately represent its role in heuristics of science.**

Good et al. (149) examined the domain of science education by critically examining recent attempts to redefine the field as the interface between science and society. The authors rejected this redefinition and supported the definition that science education is a discipline devoted to discovering, developing, and evaluating improved methods and materials to teach science (the quest for knowledge and the knowledge generated by that quest).

Yager (423) defended the definition of science education as the interface of science and society, pointing out the fallacies of an alternative definition promulgated by Good, Herron, Lawson, and Renner who examined and rejected the science/society interface definition in favor of their own definition.

Bybee (65) prepared a monograph on human ecology which provides a framework for reforming high school biology programs. The monograph provides a historical perspective, a report of a survey of adults, policies and practices that influence biology instruction, and a conceptual framework for program design, a review of curriculum materials with a human ecology focus, and background articles.

Bybee and Mau (66) surveyed 255 science educators from several nations about their views on teaching about global problems related to science and technology. Results showed that educators in most nations are in the early stages of developing programs in science that include study of global problems as part of science-technology-society topics in the science program for schools. Respondents to this survey were supportive of inclusion of global problems as part of the science curriculum.

Picker (296) described the development and use of an aquatic studies conceptual scheme which has been used in the Project COAST (Coastal, Oceanic and Aquatic Studies) at the University of Delaware. Sample concepts and results from field testing of the curriculum are included. Results showed that a conceptual scheme having widespread validity can be designed and used as a framework for elementary science curriculum construction. Also, curriculum materials derived from the conceptual scheme are at least as effective in promoting student cognition and interest as others reported in the literature.

Ault et al. (12) described the mutual benefits of cooperation between museums and schools of education.

Recognizing the importance of students' ability to read text materials in learning science, Yore and Shymansky (428) sought to define the desired outcomes of research in reading in science.

They identified five areas needing further work, including basic studies of reading processes and techniques and studies of the relationship between science reading comprehension and science achievement. This paper highlights fruitful areas of needed research.

Tamir (380) described preplanning evaluation as an additional, needed step in curriculum planning. The purpose of preplanning evaluation is to assemble a data base for curriculum development deliberations to assist in decision-making and to guard against neglect of important issues. Selected findings and conclusions from three case studies of secondary school curricular planning in Israel and Australia suggest that: (1) In elementary grades, the needs of individual students should take precedence over the demands of subject matter and society. (2) More emphasis should be given to human biology and its applications. (3) Continuous short time revision of laboratory manuals is very important.

These ten studies demonstrate the range of potential issues about which conceptual analysis of the science curriculum can occur. At the present time, science education can benefit from thougtful analysis of issues pertaining to (a) purposes of science education for different clients in an era of advancing technology, (b) selection of instructional content, (c) identification of appropriate psychological and philosophical bases, and (d) the images of science to be portrayed to students. However, these analyses must interface with one another. For authors to "write past each other," without entering into debate or deliberation is nearly as unproductive as two people "talking past each other" in a discussion of an issue. Without dialogue, articles of this type often become statements of position or exhortations to action, and they lose their effectiveness as papers upon papers accumulate.

Who can exert influence on this matter? First, authors can by (a) inviting deliberation and debate as conceptual analysis is undertaken and (b) by using a theoretical framework (i.e., a meta-theory) to guide their conceptual analyses. Journal editors can have an influence as well. For example, Good et al. expressed one viewpoint on the domain of science education while Yager, Bybee, and Picker each offered an opposing viewpoint on the same issue. However, each report appeared in isolation, and while they did not constitute a "face off" on the issue, more productive scholarship may have resulted if they had been published together with appropriate editorial commentary to highlight the debate. Further, articles could have been redrafted to confront the issues in a more analytical or deliberative fashion. Yager's article appears to be in the right direction. However, the conceptual framework underlying this article could be made more explicit and those holding opposing viewpoints could have been invited to reply to Yager's statement of position.

### Curricular Objectives

While studies in the previous section addressed curricular objectives as a consequence of broader analyses, the two studies which follow address curricular objectives more directly.

Rand (313) studied objectives for teaching college biology in the U.S. during the period between 1918 and 1982 as portrayed in the professional literature. Statements were cataloged as relating to knowledge, process, attitude and interest, and cultural awareness. Results showed that statements in process and knowledge categories were most frequently noted in the literature with "scientific methods of thinking" and "major facts, principles, or fundamentals" being most commonly reported. Also, while the number of published statements was consistently high over these years, little agreement occurred among authors regarding objectives of college biology teaching and there was little agreement among the authorship groups as to the objectives for teaching college biology.

Briley et al. (55) surveyed 170 English schools serving 13- to 16-year olds to determine the extent to which industrially relevant materials were adopted in science classes and attitudes of science teachers toward these materials in science syllabi. Findings indicated that although teachers believed that industrial materials should be emphasized, traditional science courses remain most popular.

### Teachers' Selection of Content

Only two studies were identified which focused specifically on science teachers' selection of instructional content. More work on this question is included within ethnographic studies by Jorde (202), Stockton (364), Guthrie and Leventhal (153), Mitman (256), Malkawi (243), and Moss (260). These studies are reported in the section entitled The Practice of Science Teaching.

The two studies which follow were included here because of their more specific curricular focus.

In separate, but related studies Meadows (254) and Gardner (143) investigated the status of aerospace education, and teachers' preferences for aerospace education materials in Kindergarten and grades 1 and 2 and in grades 3-5 respectively. Questionnaires were mailed to teachers in seven states. Meadows found that many K-2 teachers do not teach aerospace topics because of lack of personal knowledge on the subject and absence of appropriate materials. Teachers noted that aerospace topics were absent from most textbooks and that they desired more pictorial and audio-visual materials for teaching the subject. At the grade 3-5 level, Gardner found that: (1) A majority of the respondents indicated that they taught aerospace education at least once each year. (2) Twenty-two of the respondents never taught aerospace education. (3) Sixty-seven of 125 respondents were unaware of the educational services provided by NASA. (4) The majority of the teachers include aerospace education as a part of their science curriculum. (5) Teachers felt deficient in knowledge of available materials, latest developments in aerospace education, and background of aerospace education. (6) The major reasons for not teaching aerospace education were lack of appropriate materials and lack of personal knowledge. (7) Most respondents said they would include planet, energy, stars, and space travel as content areas in teaching aerospace education. (8) Teachers preferred workshops and in-service for continuous educational improvement in regard to aerospace education. (9) Films and filmstrips were the preferred forms of audiovisuals for teaching aerospace education. (10) Worksheets were preferred by more teachers than other types of duplicating materials.

These findings suggest that teachers' selection of content is influenced by limitations of knowledge, information, and experience. Policy makers, teacher educators and curriculum planners should recognize that these are important factors which shape the implemented curriculum in science in elementary schools.

### Program Comparisons

Studies reviewed in this section include a meta-analysis comparing program effects and five comparative studies.

Bredderman (53) conducted a meta-analysis of the effects of ESS, SCIS, and SAPA on student learning in science. Student outcomes were assessed by quantitatively combining the results of 57 reported evaluations of these programs. Thirty-two percent of the comparisons were statistically significant, favoring activity-based programs, six percent favored central groups. These results coincide with Shymansky, Kyle, and Alport's 1983 meta-analysis.

Kim (210) compared the chemistry curriculum in two Michigan high schools. Using Klopfer's categories of educational objectives in science, she found that knowledge and comprehension objectives predominated with a small percentage of application and scientific inquiry I. Scientific inquiry II, III, and IV were virtually unrepresented among the objectives of two regular and one advanced placement course. In the analysis of chemistry topics, the two regular programs planned to emphasize chemical laws, energy relationships and equilibrium in chemical systems, and atomic and molecular structure. The advanced placement program planned to emphasize chemical materials (15.3 percent), chemical laws (15.3 percent), energy relationships and equilibrium in chemical systems (24.7 percent), and atomic and molecular structure (16.9 percent) in the total instruction hours. All three programs rarely taught general topic categories (0.0 to 7.4 percent). In the analysis of intended teaching methods, the two regular programs planned to use mostly lecture, student experiment, problem solving and test. The advanced placement program planned to use more student experiment methods (31.2 percent) than lecture method (29.2 percent) in the total instruction hours. Analyzing student interests, lecture, problem solving, and Socratic method classes showed less positive outcomes than classes involving experiments or lectures. Manual skills captured greater student interest than knowledge and comprehension.

Chamberlain (77) compared performance in A-level science examinations of students who took an integrated science course (SCISP) with students who studied the separate subjects of physics, chemistry, and biology to O-level standard. Results showed no significant differences between the performances of the two groups.

Weigand (414) explored an interdisciplinary approach to teaching art and natural science in high school to determine if this approach affected students' ability in the cognitive, performance, and affective domains. Two groups whose members were assigned at random were utilized. The control group received instruction based on the New York State Education Department's publication, Studio in Art: A Comprehensive Foundation Course. The treatment group received instruction in an integrated Art/Science Curriculum. The instruments used to measure the dependent variables were The Scientific Attitude Inventory (Moore and Sutman, 1970), The Attitude Inventory

(Eisner, 1966), and the Integrated Art/Science Inventory (Weigand, 1983). Data concerning student performance in art were generated from judged scores of student art work. The independent variables of age and sex were considered during data analysis. The results revealed that boys in the treatment group consistently developed more positive attitudes toward science than boys and girls studying the standard studio art curriculum. The study also showed that the treatment had a positive effect on the attitude toward art and the ability to recall art related information for all subjects tested. The study further demonstrated that the treatment had no negative effect on the art performance of all test subjects.

Kyle et al. (221) compared attitudes of elementary teachers and students of teachers using Science Curriculum Improvement Study (SCIS) with those using other programs and reported that SCIS teachers spend more time teaching science and students indicated preference for the SCIS process approach.

Hill and Redden (174) studied fourth-grade students' learning of the SCIS unit "Sub-Systems and Variables" with students in Australia and the United States. Results showed similar difficulties for students from both countries in learning system concepts.

The six program comparisons reported above add useful information to our knowledge base about science education. Studies by Bredderman, Kyle, et al., and Hill and Redden highlight the benefits and difficulties arising from teaching of inquiry-based elementary science. Overall, however, these data support the contention that SCIS, SAPA, and ESS were effective programs for teaching elementary science, in spite of difficulties encountered by teachers and students.

Findings reported by Kim provide a detailed analysis of the planned and implemented curricula in high school chemistry as well as some data on students' responses to their instruction. Since these data represent actual practices in chemistry instruction at the high school level, they deserve thoughtful attention from instructional supervisors and curricula planners.

Weigand's study of the integration of science and art appears to address a novel program. People interested in subject matter integration in secondary schools will find this a useful, informative study.

### Curriculum Development

Two dissertations were reported in 1985 which studied development of new curriculum materials.

Pankiewicz (292) studied the effectiveness of an instructional module in organic chemistry on junior high school students knowledge, attitudes, and interests. Selected predictors of achievement were also included in the study. A control group design was incorporated with the control group studying a popular text. Results showed gains in interest and achievement in the expected directions and mixed results regarding attitudes and knowledge of processes of science. Pretest scores and prior grades were good predictors of posttest scores.

Maillett (242) conducted a study in which a physical oceanography unit for junior high school was developed and evaluated. The unit was tested in six junior high schools; the instructional duration was 19 days. Students were pretested, posttested, and administered a Piagetian style test of developmental level. There was a significant improvement in student performance from pretest to posttest. Student performance by developmental level showed that concrete operational students scored lowest while formal operational students scored highest. There was no significant difference between the scores of males and female students. There was a significant difference for both knowledge level and higher level questions when the students were separated by developmental level. Specific relationships between Test of Formal Operations items and posttest items were not found, but specific factors within each were identified.

It is unfortunate that more studies of curriculum development have not been undertaken. It is a complex process, with an interesting social dynamic which is worthy of study. More research in this area would be beneficial.

### Curriculum Implementation

Five studies included in this section describe and assess the processes of implementation of four different curricula in Israel, Thailand, and Trinidad and Tobago, and the United States.

Dreyfus, Jungwirth, and Tamir (113) investigated the main concerns of teachers teaching the Israel High School Biology Project (IHBP). This program, implemented about 15 years ago, is an adaptation of the Biological Sciences Curriculum Project Yellow Version. Areas examined include how teachers perceive the program and what changes they would make. Results showed that teachers: (1) supported the laboratory/inquiry approach; (2)

accepted the physiological stance of the program; (3) considered the human, social, and ecological aspects of the program desirable; (4) advocated flexibility and creativity-promoting activities to meet student needs; (5) adapted their emphasis and approach to respond to external examination requirements in both positive and negative ways; (6) would like to have greater involvement in curriculum development, but relied heavily on textbooks; and (7) blamed centralization of authority, administrative organization, financial constraints, and extended examinations for the difficulties and dissatisfaction with teaching.

Sungkatavat (371) studied the nature and extent of the implementation of the tenth grade IPST Biology Program in Thailand, using the Concerns-Based Adoption Model. Assessments were made of 126 tenth-grade biology teachers from 114 schools in Bangkok on Stages of Concern, Levels of Use, and Innovation Configuration, and Locus of Control. From the data it was concluded that: (1) The most intense concerns were informational and personal with high refocusing concerns. (2) Teachers identified as exhibiting external locus of control had significantly higher intensity on awareness, management, and refocusing concerns than the internal locus of control group. (3) There was only a slight difference in the Stages of Concern profile with respect to number of years of teaching the IPST program. Teachers aged 40 and older had lower intensity than younger teachers on every stage of concern, except the consequence concern. (4) One-fourth of the teachers were using the program in a routine way. (5) The majority of biology teachers were using the program in an acceptable fashion as the developers intended. (6) There were no significant differences between teachers identified in internal and external locus of control on Levels of Use and Innovation Configuration. (7) Experienced teachers had higher Levels of Use scores. (8) Teachers with higher degrees had high Levels of Use scores. (9) Female teachers and teachers aged 40 and older operationalized their uses of the innovation closer to the developer's ideal than did male and younger teachers respectively on evaluation of student outcomes, relative emphasis on process vs. content, and teacher role in the laboratory. The results establish the fact that the Concerns Based Adoption Model can provide developers and change facilitators with an understanding of the process and will aid in the better management of implementation efforts.

Howe and Stanback (182) presented a review of research on the Intermediate Science Curriculum Study (ISCS). Areas addressed included: (1) teacher education, (2) student cognitive and affective outcomes, (3) teacher and student facilitative characteristics and behaviors; and (4) ISCS instructional materials. Their analysis produced the following interpretations: (1) Initial concerns over the ability of teachers to adapt to the individualized approach required by ISCS appeared to be unwarranted as many, but not all, teachers who had appropriate training were able to adopt the methods. (2) Pupils also adapted to the approach, and attitude measures were either neutral or positive. (3) Cognitive outcomes resulting from ISCS were less positive, especially for low-ability students. (4) ISCS has never been systematically evaluated.

Nowell (273) conducted a case study of the implementation of the Intermediate Science Curriculum Study (ISCS) in two junior high schools in a suburban school district during a five-year period. The purpose of the study was to determine events resulting in acceptance of the program by the science teachers involved. Results indicated that the change process encompassed three distinct phases: awareness and interest, trial and evaluation, and adoption and use. Also it was found that (1) Teachers' attitudes are related to the type and frequency of curriculum change activity taking place. (2) Positive teacher attitudes are found to occur in situations where (a) teachers have a common goal and are given an opportunity for successful input into the decision making process, (b) administrators and/or supervisors provide supportive leadership, and (c) organizational structures permit individual initiative and provide the necessary resources. (3) Negative teacher attitudes coexist with (a) the inability of teachers to have successful input into the decision-making process, (b) lack of support from leadership figures, and (c) expressed dissatisfaction on the part of peers. (4) Strong leadership does not necessarily change attitudes but it can reinforce those already extant.

Fraser-Abder (136) reported on work of adopting Science: A Process Approach for use in Trinidad and Tobago. During a six-year period, approximately 700 teachers were involved in curriculum writing and implementation. An evaluative study of this program is also described. Findings revealed that high scores have been achieved by students and that teachers evidenced significant interest and participation levels in the program.

These five studies appear to offer support for familiar models of curricular innovation. When teachers understand and accept the aims of a program and are provided with the training and resources to implement it, the results are satisfactory for them and their students. While the previous statement may be part of our "practical wisdom" as a result of research and direct experience, two points are relevant: First, it is reassuring that these five studies reconfirm this principle. Second, given its generalizability, why do we see it violated so frequently in the practice of schooling? Certainly, school leaders and others responsible for policy decisions comprehend the principle and yet it does not regularly guide implementation of innovations. Studies of decision making and policy setting may shed light on reasons which underlie actions that ultimately are counterproductive.

## Textbooks

Sixteen studies reviewed here examined a variety of questions pertaining to textbooks and the scientific content and social messages that are presented by them.

Horak (179) conducted a meta-analysis to analyze the effects of different types of aids on learning science concepts from textual materials. Results indicated that most students can be expected to benefit from forms of textual structuring that aid them in selecting the important concepts and that also aid them in making internal connections within the presented materials.

In a comprehensive review of science education research, Holliday (176) found a lack of studies relating to the act of reading. He attributed this to dismissal, by many science educators, of instructional questions related to reading and textbooks. Even though many teachers use texts centrally in instruction, attitudes and practices of science educators have exacerbated the gap between research and teaching. Holliday suggests closing the gap among researchers, science teachers, and reading educators. Three reading-related domains of potential interest to these individuals include: How science educators can compose, select, and use science textbooks and other materials; the theoretical and applied relationships between intellectual process skills of science and reading skills; and the use of such non-school print materials as "Newsweek" and more scholarly materials such as "Scientific American." One mechanism for achieving these goals is for science and reading educators to acquaint themselves with each other's theoretical orientations and not be limited by theoretical issues and methodological techniques.

Koval and Staver (217) conducted a comparative study of textbook terms to determine what high school science skills are necessary for success in associate degree physical science courses. Results indicate that although enrollment in technology-training programs is increasing, high school textbook treatment of terms remains inadequate preparation f[illegible] or college programs.

Pratt (304) reviewed recent thinking about the role of mathematics and problem solving in science courses and then conducted a survey of the mathematical content of secondary science textbooks.

Konopak (215) studied the effects of text characteristics on word meaning from high school physics textbooks. In a study that compared the effects of a text that used an informal prose style that depended on "analogies and models" for word comprehension and a second text which used a formal prose style that relied on explicit definitional information, it was found that; (1) prior knowledge influenced immediate and delayed comprehension; (2) formal prose elicited better quality definitions and aided in retention, and (3) that passage contexts were more memorable. Results suggested that preparing students for formal study is more effective than providing less precise, "familiar" texts that do not provide explicit definitional information.

Barber and Tomera (17) surveyed 156 Illinois biology teachers regarding teaching of ecology. Results showed that textbooks are major factors in determining teaching of ecology, relevant societal issues, and environmental literacy. Data are included on textbooks used, extent of use, instructional methods, ecological concepts taught, and environmental problems.

Rosenthal (323) studied the treatment of the topic of evolution in high school biology textbooks published between 1963 and 1983. Twenty-two high school biology texts were reviewed using a content analysis of twelve social issues, including evolution. Results showed that texts published prior to 1979 contained a mean of over 13 percent of pages devoted to evolution, whereas texts published between 1979 and 1983 contained a mean of 9.9 percent of pages. Between 1963 and 1983 the mean number of pages devoted to evolution in the texts studied decreased from 52.4 to 32.5, which is partially attributable to decreases in text size during the period. It also was noted that treatment of other societal issues decreased over the period as well.

Cho et al. (79) analyzed three high school biology textbooks to determine possible sources of misconceptions and difficulties in learning genetics. Inadequacies were found regarding sequencing of topics, relationship of meiosis and genetics, inadequate development of understandings of basic concepts of meiosis and genetics, uses of terms, and mathematical elements in genetics.

**Seeber** (338) examined the presence and function of illustrative materials in ninth-grade social studies and science texts. Results showed that reading ability had the most significant effect on free and cued recall scores for both social studies and science. Illustrative condition had no effect on social studies scores. Illustrative condition had a significant effect on science scores with the no illustrative materials condition providing the highest scores on immediate free recall and the explicative illustrations providing the highest scores for delayed cued recall.

**Hickey** (173) investigated the relationship between textbook structure and students' achievement in seventh-grade science. It was found that altering standard textbook designs resulted in improved achievement.

**Covey and Carroll** (94) studied the effects of illustrations in sixth-grade students comprehension of subject matter presented in textbooks. Results showed that pictures facilitate comprehension.

**Montgomery** (259) examined the relationships that existed between the publishers' readability levels of five elementary science textbooks and the readability levels established by the Fry Readability Graph, the Dale-Chall Readability Formula, the Cloze technique, student judgment, and teacher judgment. The study was conducted with 131 pupils in grades 4-6 and selected teachers. Results call into question the use of the Cloze technique for assessing readability of science texts.

**Williams and Yore** (420) studied the relationships between page format, grade level, gender, content, and elementary school students' ability to read science material presented in a popular science textbook. The study was conducted with students in grades 4-6 using the Cloze procedure. Significant relationships were found between Cloze scores and both grade level and content. Biological topics were most difficult in terms of readability. A significant interaction effect was noted favoring older male students. Readability was assessed at "near frustration level." Authors suggest changes in text design by publishers and that teachers should provide students with direct instruction on the use of visual materials in texts to increase learning.

**Fumo** (140) applied Piagetian theory to the analysis of science and mathematics textbook concepts. One-third of the chapters found in levels one, two, four, and five of the science and math series were analyzed. The findings (1) demonstrated the applicability of Piagetian theory for curriculum evaluation and design, (2) revealed consistencies as well as inconsistencies between learners' developmental stage and concept stage in the textbooks analyzed, and (3) indicated that the level of the concepts presented was typically above the developmental stage level of the learner for which the text was written.

Lipschitz (234) examined strategies used by fourth grade pupils for comprehension of extended and holistic metaphor/analogies in science textbooks. Three strategies (verbal, pictorial, and exemplar) were examined. Fourth graders were categorized as proficient, average, and unskilled, based on reading scores. Results suggested that: (1) Restructuring the metaphorical sentence and training in strategy skills should improve comprehension skills for science information. (2) Reevaluation of science materials should help identify the kinds of reasoning strategies and inquiry process skills needed for successfully completing metaphor/analogies and related science tasks.

Powell and Garcia (301,302) studied the portrayal of women and minorities in seven contemporary elementary science series. An evaluation instrument was used to assess the portrayal of 5900 illustrations. Results showed that female children were represented with greatest frequency. Minority children and adults were represented less frequently than their non-minority counterparts. Textbooks appeared to display science positively for most societal groups, but minorities were underrepresented and illustrated with a limited number of career roles.

These findings give important evidence regarding (a) the strong influence that textbooks have on science instruction in the U.S. and (b) how little is known about designing and using textbooks so that students of various ages and abilities can learn effectively from them. Given the influential position texts and text publishers have in shaping science curricula, teachers' instructional approaches, and students' learning, it is encouraging that sixteen studies have been reported pertaining to various text-related issues.

At present, we know relatively little on this topic. Initial research findings, such as reported by Carey and Carrol and by Seeber show conflicting results about the effects of graphics on students' learning. Konopak's finding that formal text structures are more effective than analogies and models seem counter-intuitive while findings by Horak, Cho et al., and Hickey suggest the need for reexamination of the principles which guide text authors and publishers regarding decisions about content, format, and other critical matters. Fumo's finding that the conceptual level of texts exceeds the cognitive developmental level of the students for whom the books are intended raises several questions about their utility as teaching aids, how teachers should adapt instruction based on these texts, and how publishers should modify texts to improve their effectiveness with students and teachers who will use them. Taken together, these sixteen studies raise many more questions than they answer. However, this is not a criticism of the studies. Rather, it reflects the status of current knowledge on this important, complex topic.

More research on textbooks is needed. To reiterate Holliday's assertion, increased attention to research on the design and use of textbooks could strengthen connections between research and practice. But more importantly, our profession needs more information about how students and teachers can use textbooks more effectively, and how better textbooks can be designed to enhance learning in science. Perhaps one of the most important studies relevant to textbooks was reported by Roth (324) which is cited in the section of this report that deals with conceptual change teaching. This study suggests the need for restructuring textbooks to account for expected misconceptions which students bring with them to science classes. This is a revolutionary suggestion that needs thoughtful consideration.

## The Practice of Science Teaching

Several studies pertain in various ways to the practice of science teaching in schools. This section begins with descriptions of science teaching practice and studies of exemplary programs. Other characterizations of practice include studies of perceptions of the workplace in which teachers labor, studies of classroom environments and teacher effectiveness, influences of homework and examinations, and studies of patterns of enrollment in science.

Topic categories are (numbers of studies in each category are shown in brackets):

A. Descriptions of Practice [14]

B. Studies of Exemplary Programs [3]

C. Perceptions of the Workplace of Science Teaching [3]

D. Classroom Environments and Teacher Effectiveness Research. [6]

E. Studies of Homework and Examinations [4]

F. Enrollment Patterns in Science. [5]

### Descriptions of Practice

Teters and Gabel (388) conducted a national survey of needs and practices in teaching elementary science. Survey topics included instructional topics, criteria for content selection, methods of instruction, curriculum/program used, factors that help and hamper instruction, time requirements for science, time devoted to instruction in science, and adequacy of science instruction in schools. These and other topics are discussed in terms of six demographic variables.

Aikenhead (2) reported on a collection of empirical studies emphasizing teachers' practical knowledge. Results showed that understanding teachers' practical knowledge has important implications for teacher educators, for researchers who are attempting to understand practice, and for those who wish to communicate research findings to teachers.

Doyle, Sanford, and Schmidt-French (112) contrasted academic tasks in secondary science classrooms using a case study approach. Results showed that secondary science classrooms vary considerably in learning opportunities for students. Suggestions are given for the use of the academic task model in addressing specific themes and enduring problems of practice in planning research in science education.

Using ethnographic techniques, Gallagher and Tobin ( ) studied the relationship of (1) the instructional and managerial roles of 15 teachers in Western Australia, (2) interactions between teachers and students, and (3) student engagement in the prescribed learning tasks. Findings showed that most teachers adhered closely to prescribed curriculum content and placed heavy emphasis on preparation for both teacher constructed and external examinations. Form and routines appeared to be more important than comprehension to both teachers and students. Classroom interactions between teachers and students were limited to 5-7 target students in most classes with remaining students being passive participants or non-participants during whole class interactions which predominated.

Using data from this same study, Tobin and Gallagher (142) showed that a small number of students played an important role in secondary science classes. Observational data showed that interactions between teachers and students, during whole class instruction, was limited to five to seven able, outgoing students, called target students, while the majority of students were only occasional, often passive, participants. Two groups of target students were identified: (a) those who were self-selected and (b) those selected by the teachers. Both groups of target students tended to have a high internal locus of control and scored high on tests of formal reasoning ability. Gender differences favoring boys were noted in grades eight through ten but were not found in grades eleven and twelve.

Roadrangka and Yeany (319) examined relationships among type and quality of implementation of science teaching strategy, student formal reasoning ability, and student engagement. Classroom observations of five teachers and selected students in 39 different class sessions generated teaching strategy and student engagement data. Formal reasoning ability was measured, using the Test of Logical Thinking. Results showed that type and quality of teaching strategy related significantly and positively to student engagement. Overall, the type and quality of teaching strategy accounted for 37 percent of the variance in engagement, whereas, differences in reasoning ability only accounted for 3 percent of the variance.

Jorde (202) conducted an ethnographic study of a racially mixed, urban high school to gain insights into the social and academic environment pertaining to science. More mature senior science faculty taught advanced courses to classes comprised mainly of white and Asian students. Basic science courses enrolling students meeting a two-year graduation requirement in science were more difficult to teach due to discipline problems. These were taught by less experienced teachers. College bound students generally had more favorable comments on science classes than did non-college bound students. Both groups of students tended to give negative impressions of scientists or careers in science. Additional science faculty, hired to accommodate increased science enrollments, may have a positive impact on the science department by providing energy for introductory level curriculum development.

Malkawi (243) conducted a case study of chemistry teaching and learning in a tenth grade classroom in Jordan as a way of understanding the quality and effectiveness of science instruction. The study addressed three main components of the teaching-learning process: program materials, actual instruction, and students' learning. The quantity of subject matter was found to be too much to cover in the time available. In order to cover this amount, the teacher in this study excluded the experimental part of the program and was very demanding in the full utilization of classroom time. The textbook presentation of some topics was found to be confusing, and the teacher faced problems in teaching them. In some cases, she missed the meaning of the textbook and assigned other meanings derived from prior experience. Teaching and learning in this classroom were limited to the conceptual knowledge of the course. Many students had problems in learning certain topics as well as general principles and main ideas. They succeeded, however, in learning most of the specifics of the subject matter. Evidence was presented to show that this classroom was representative of many other classrooms throughout Jordan.

Stockton (364) conducted an ethnographic study of science classrooms focusing attention on their generative (fostering students' development ) and replicative (reaffirming students' origins and background) character. The study found that school effects are closely linked to teacher expectations. Generally, lower ability classes had more replicative characteristics and higher ability classes more generative characteristics. Curriculum-in-use, rather than curriculum materials, determined whether or not schooling was generative in a particular classroom. Other findings indicated that students typically had generative views of schooling, looked upon school as the center of their social activity, preferred active learning experiences, and wanted teachers to relate to them as people first and pupils second. A majority of students planned to continue schooling beyond high school, and their primary concern was grades.

Guthrie and Leventhal (153) conducted a three-year ethnographic study of six high schools to determine opportunities for acquisition of scientific literacy by both college bound and non-college bound students. Findings showed that: (1) Teachers gave priority to facts, methods, and attitudes. (2) Scientific literacy components did not form an integral part of the curriculum. (3) The size and make-up of the school population influenced course offerings, teaching load, and science requirements. It was suggested that considerations should be given to ways of increasing the range of student choices of science courses and of improving the quality of science instruction for all students.

Mitman et al. (256) reported on a study which examined what combinations of teacher, student, and curricular variables were associated with more effective life science instruction at the intermediate level. The conception of effectiveness was guided by the normative framework of scientific literacy and by student growth on science outcomes. The definition of scientific literacy used consisted of five components; (1) explaining science content, (2) relating to science as a social historical process, (3) relating to science as a reasoning process, (4) relating science and society/technology, and (5) positive attitudes toward science. Findings from students and teachers in 11 classes were: (1) Teachers generally used a typical pattern of academic instruction, relying heavily on recitation, seatwork, and laboratory exercises. (2) Students perceived that teachers made relatively little use of the scientific literacy components other than explaining factual content. (3) Worksheets were the most commonly assigned activities. (4) Student attitudes toward science generally declined over the academic year, while science knowledge, understanding, and reasoning skills increased.

Healy (169) conducted a case study of one teacher's use of writing in a seventh grade science class as a tool for enhancing student learning of subject matter. The study also documented the teacher's attempts to both introduce new types of writing assignments in her class and to treat this writing in ways more congruent with her growing understanding of her own writing processes. The findings showed that the students rarely used these writing assignments to make personal connections with new subject matter, to reconstruct it using their own language, or to raise speculative questions about the material. Possible reasons for this finding include the teacher's conflicting goals for her students' learning of science, her uncertain understanding of the role written language played in this learning, and her inconsistent instruction for and follow-up to the writing assignments she made. This latter inconsistency was found during all the stages of the writing assignment cycle. This study revealed a basic disjunction between the teacher's desire to introduce new writing assignments to aid her students' learning and her practical knowledge of how to introduce and follow up such assignments effectively with her students.

Moss (260) studied the perceived application of basic mathematics skills and science strategies in secondary vocational home economics. Results showed that home economics teachers: (1) perceive basic math and science as an essential part of subject matter which they teach, and (2) employ specific skills and strategies to a lesser extent than they perceive should be incorporated.

These fourteen studies provide a relatively systematic documentation of "hunches" which science educators have discerned from experience. For example, Roadrangka and Yeany found that the type and quality of teaching accounted for 37 percent of the variance in student engagement. Guthrie and Leventhal and Mitman et al. noted that scientific literacy is not an integral part of secondary science instruction. Reports by Stockton, Jorde, and Gallagher and Tobin showed that secondary science teaching has elitist qualities in which able students are nurtured and less able ones become progressively lost in a tangle of partially understood content. Malkawi showed that the textbook and the teacher sometimes lay at the base of students' misunderstanding. And in one way or another, nearly all of these studies showed that teachers and students placed more emphasis on learning facts and "covering" content than on building comprehension. Moreover, practical application of science to student's daily lives is an idea that is notable by its absence from these descriptions of practice.

There were a few surprises, too. Roadrangka and Yeany showed that only three percent of the variation in student engagement was attributable to differences in students' reasoning ability. On the other hand, observations by Tobin and Gallagher show that most practicing teachers appear to believe that reasoning ability is a key factor in students' engagement. Also, Jorde showed that even able students held negative impressions of scientists and scientific careers.

These studies represent a source of needed information about the character of science teaching practices, yet only one of the studies explored elementary science teaching. Clearly more descriptions of practice at that level are needed, too. Future research on science teaching practices are needed to add an important dimension; that is, while it is useful to have descriptions of events in schools, it is essential to learn about the forces, both real and perceived, which underlie these events. If we are to alter practice in desired directions, it is essential that we know both what is presently occurring in schools and the reasons which lie behind the events we observe. With this knowledge we will be able to build upon the "wisdom of practitioners" instead of initiating reforms in ways that frequently disregard this important information.

## Studies of Exemplary Programs

Three studies of exemplary science programs were reported, all originating at the University of Iowa. These studies bear similarities to effective-schools research.

Vargas-Gomez (400) compared science teachers' opinions and students' attitudes between samples chosen randomly and drawn from exemplary science programs. Teachers were assessed regarding their view of the importance of specific professional competencies and the optimal place for their development. Students were surveyed about their attitudes toward teachers, classes, usefulness of science study, and what it is like to be a scientist. The data showed that teachers from exemplary programs were significantly different from the random sample in the following ways: (1) extent of their scientific and pedagogical preparation, (2) extent of in-service experience, and (3) involvement with professional societies. Students in exemplary programs were more positive in that their teachers made science exciting, and teachers encouraged them to share their own ideas, including questions. Further, students saw their science classes as being more interesting and they felt more successful than students from non-exemplary programs. It was concluded that students in exemplary programs had experiences in science that were more positive and provided more accurate views of careers in science.

Bonnstetter (49) studied characteristics of 231 teachers associated with 53 exemplary programs, and compared them with science teachers in general. Data included teachers' responses to the Science Attitude Inventory, and an adaptation of the 1977 National Survey of Science, Mathematics, and Social Studies

Education. When compared with the general population of teachers, key teachers in exemplary programs were found to be older and have more teaching experience, more likely to hold a masters degree or higher degree, and have more recent involvement in college credit courses. They were more likely to find other teachers, subject specialists, inservice programs, professional organization meetings and journals as good sources of information. These teachers read two or more professional journals regularly and demonstrated high enthusiasm for teaching. Their curricula tended to be locally developed, not textbook centered. They used more hands-on manipulatives and laboratories and lectured less than teachers in general. Inservice training for staff was important to them and they maintained close communication with local colleges and universities. It was also determined that exemplary programs neither exactly modeled the desired state of science education nor did these teachers always employ the most appropriate teaching strategies.

Bonnstetter and Yager (50) surveyed 114 teachers associated with exemplary elementary science programs on longevity, confidence, professional involvement, familiarity of curricular materials, inservice, and teaching methods. Comparison with a national sample indicated that these teachers had long-term program involvement, a great deal of confidence, and activity-oriented classrooms.

This line of research is a very promising one, as science teaching would be enriched if we were to understand the characteristics of excellent teachers and programs more thoroughly. As a fundamental step in this research area, renewed attention is needed regarding the definitions and criteria of excellence that are used in identifying excellent teachers and programs. Moreover, more detailed studies, using ethnographic methods, will be helpful in understanding what characterizes excellent teachers and programs, how they got that way, and how (and if) they continue over time. These studies, coupled with other studies which appraise science teaching qualitatively, will benefit our knowledge as teacher educators and influence educational policy.

### Perceptions of the Workplace of Science Teaching

Three studies examine teachers' perceptions of their work environment.

Bentley (26) studied secondary science teachers' perceptions of the conditions of good science teaching. Using a 54-item questionnaire based on the NSTA publication "Conditions of Good Science Teaching in Secondary Schools," data were collected from 94 teachers. Their degree of acceptance of each condition and perception of implementation in their own schools were analyzed. The findings showed that the teachers who responded perceived a majority of the items as being important to good science teaching; however, they did not perceive these conditions as being implemented in their schools.

Douglass, Matyas, and Kahle (111) reported on a 1982 survey of perceptions of professional equity. Surveys were sent to 1051 members of the National Association of Biology Teachers. Using data from 509 respondents (48 percent), the authors found inequality between males and females in several professional areas including salary, paid consulting opportunities, teaching assignments, research activities, and administrative assignments. However, respondents did not perceive that preferential treatment existed regarding salary and promotion.

Rubba and Becker (326) surveyed 228 Illinois principals to determine the qualities they examine when hiring mathematics and science teachers. Content area knowledge, area of certification, and personality characteristics were of higher priority than sponsoring extra-curricular activities, references, and minor areas of certification.

These three studies tap an area of potential promise. We have little systematic knowledge about the quality of the workplace of science teachers. Even less is known about how the work environment of teachers influences their effectiveness, their professional growth, achievement of their potential, or their continuation in, or withdrawal from, the field. Quality of work life has been shown to have important effects on productivity in the private sector. We could benefit from studies which assess its influence on teachers. Moreover, pragmatic definitions of "quality of work life" based on science teachers' viewpoints might be a useful starting point. Future research in this area will be enriched by collaboration of science educators with colleagues from sociology, industrial psychology, labor-management relations, and similar fields.

## Classroom Environments and Teacher Effectiveness Research

The five studies in this section were grouped together because of a common focus on effective teaching practice. Their connections with the three previous sections enlarge our comprehension of the world of practicing science teachers.

Fisher and Fraser (128) reported on a study of the use of short forms of classroom environment scales in assessing and improving the psycho-social environment of science classrooms. Three instruments were used. The Classroom Environment Scale (CES) is a 24-item measure requiring a true or false response for each item. The My Class Inventory (MCI) is a 25-item measure requiring a yes or no response for each item. The Individualized Classroom Environment Questionnaire (ICEQ) is a 25-item measure requiring a Likert-type response for each item. Case studies involving use of the CES in a ninth-grade class and the MCI with sixth-grade students are included. Steps followed in both studies included: assessment, feedback, reflection/discussion, intervention, and reassessment. In the junior high study, improvements occurred for the two dimensions on which change had been attempted.

Lederman (229) studied the relationship between teaching behavior/classroom climates of 18 high school biology teachers and changes in students' conceptions of the nature of scientific knowledge. Changes in conception were measured using the Nature of Scientific Knowledge Scale. Classrooms in which students exhibited high levels of change on this scale were characterized by frequent, inquiry-oriented questioning, little emphasis on rote memory, decreased seat work, and increased emphasis on depth, breadth, and accuracy of subject matter. In addition, teachers in these classrooms were more pleasant, supportive, and had established better rapport than those of the "low" group. Finally, implicit references to the nature of science were more commonly found in the "high" group.

Nkpa (271) studied factors related to clarity of biology teaching in Nigerian secondary schools. Facilitative and inhibitive behaviors of teachers were identified through analysis of tape-recorded lessons and were associated with "clear" and "less clear" teaching. A model of clarity was formulated and validated; the model comprised two critical components which were expected to generalize across topics, subject matter content, teaching methods, and teacher characteristics. These were (1) the simple translation of content from the teachers' level to the language and conceptual level of students and (2) appropriate pacing. Some behaviors in the model were thought to be generalizable across teacher characteristics and topics. These behaviors included the adequate selection of relevant content and differential emphasis on critical content to the exclusion of peripheral information, questions used to ascertain whether students understand, pauses for student questions, avoidance of vagueness, and unexplained content. Other important behaviors in the model were expected to be dependent on teacher characteristics and topics. The facilitative effect of observation questions and the inhibitive effect of pronouns with ambiguous referents and use of non-synonyms as synonyms were thought to be particularly relevant to biology teaching.

Wheatley et al. (418) examined the characteristics of successful interaction between students and teachers in marine science projects. The report described initial steps to determine characteristics of students and teachers with award-winning marine science projects selected by the National Marine Education Association. Thirteen student/sponsor pairs (1 zoo employee, 1 marine research employee, 11 high school teachers) completed instruments assessing learning/teaching styles, attitudes, and mental development. Results are not reported.

Schein (331) examined the issue of student achievement as a measure of teacher effectiveness. He identified three inherent problems: (1) great variability in initial student capabilities, (2) teaching to the examinations, and (3) regression effects. In a pilot study, it was demonstrated that external observers and the use of pretest and posttest could avoid these problems.

Fraser (135) recently published a book which summarizes classroom environment research. To complement this resource, there is a need for thoughtful analysis of teacher effectiveness research from a science education perspective. The educational purposes underlying much of the literature in the domain of teacher effectiveness research are not entirely compatible with the educational purposes of school science; and while the findings of this research may provide science teachers and science teacher educators with important knowledge about effective teaching strategies, they must be interpreted in the framework of the educational purposes which science is attempting to fulfill.

### Studies of Homework and Examinations

We know intuitively that homework and external examinations have a strong influence on the behavior of students and teachers and on students' 'learning. However, little systematic knowledge has been reported on the influence of homework and examinations in science education. The four studies which follow add to our knowledge of practice in these important areas.

Tamir (383) defined a conceptual framework for studying homework as an aid to science learning in secondary schools, and then applied it to three case studies of practices in Israel secondary schools. Students' attitudes toward homework also were examined.

Results showed that students generally believed that homework was important in fostering understanding and promoting learning. However, a majority of students did not perceive homework as contributing to enjoyment of learning, although differences were found between Arab and Jewish students which may be related to differences in students' values. The conceptual framework and initial studies provide foundational work for subsequent study of the role of homework in promoting science learning and attainment of other objectives of science instruction.

Kinyuy (211) studied the relationship between the general certificate examinations in physics and the objectives of science teaching in Cameroon. The purpose of this research was twofold: First to develop a valid and reliable classification instrument that could be used for the purpose of relating physics test items to the objectives of science/physics teaching. Second, to establish the extent and degree of consistency with which the Cameroon General Certificate of Education Advanced Level (CGCE A Level) Examinations in Physics of 1978, 1981, and 1982 tested for the students' achievement of each one of the thirty-one component objectives. Results showed major emphasis on examination on recall of textbook knowledge. Further information about the examination is provided.

Ekpo (115) studied the articulation among the syllabus, two textbooks, and the final examination for the Nigerian school certification biology curriculum. The Method of Analyzing Content Sequence, Doyle's Typology of Tasks, Bloom's Taxonomy of Educational Objectives, and three readability formulae were used to analyze the instructional and evaluation components. Data were collected from 86 Class Five biology teachers from five states in Nigeria. The results of this research show that there was articulation within the Nigerian school certificate biology curriculum. But Nigerian biology teachers were not satisfied with the curriculum. They did not consider the syllabus to be organized or sequenced in logical and teachable ways. They did not consider text content to be explicit. Furthermore, they indicated that gaps existed between syllabus and texts in the areas of genetics and ecology. Finally they did not consider the final examination to be consistent with the cognitive levels of the students.

Tall (378) assessed the impact of recent changes in science education in England on course offerings and science entry examinations. Results showed more balanced selection of science courses and an increase in female entries.

These four studies constitute only a small addition to our knowledge of a relatively uncharted area. Science education at secondary and tertiary levels could benefit from systematic knowledge about homework and testing. A meaningful research agenda on these topics should be formulated and enacted.

### Enrollment Patterns in Science

Studies of enrollment patterns in science can enhance our understandings of school practices. The seven summaries which follow help us understand not only the character of enrollment patterns, but also, the reasons which underlie them.

Yager and Zehr (424) surveyed 132 U. S. graduate programs in science education to determine enrollment trends from 1960 to 1980. Major trends are described for doctoral students, faculty financial support, and employment of graduates with doctoral degrees from the 35 largest institutions. The number of undergraduate programs in science education has grown from 84 to 104 over the 20-year period, while the number of Master's and doctoral programs has increased from 32 to 126 and 23 to 67 respectively. However, the peak numbers of graduates were found in 1975 at all three levels.

Khoury (208) and Khoury and Voss (209) used a path analytic model to assess the relative impact of different factors on science concentration decisions made by 237 tenth-grade students. Included in the model were selected demographic and socioeconomic factors, academic abilities factors, indicators of home and school support, attitudes toward science, and students' science enrollment plans. Findings showed that even high achieving females experienced less enjoyment than did males in learning science. Attitudes and past performance appeared to influence course plans for both males and females. Males based course plans on achievement, motivation, and family climate; while teacher support, achievement, and usefulness of science were the key factors in females' choices about courses of study..

Khalili (207) studied factors responsible for low science enrollment beyond a two-year science requirement in a specific American high school district. Using the Test of Science Related Attitudes and an instrument of his own design, 336 students enrolled in social science classes in three high schools served as the research sample. Significant differences were found between sexes and between students who continued in science and those who did not on the following measures: attitudes toward science, self-evaluation of ability to do science, and perception of past experience with science. Comparisons of science students with non-science students showed that the former tended to enjoy science more, rate their abilities to do science higher, perceived past experience with science better, and rate the social implications of science higher. Paradoxically, the non-science students scored better on adoption of scientific attitudes. Males tended to have more leisure interest in science and rated their abilities to do science higher than did females. Females tended to have a better perception of past experience with science. In students' view, science enrollment could be increased by emphasizing the applications of science to daily life, minimizing examinations' weight in grading, simplifying abstract concepts, and providing more individualization.

Shepard (345) studied factors responsible for the non-election of physics by eligible secondary school students in the Southeastern United States. Using a questionnaire of her own design, it was found that the best predictors of election or non-election of physics were of a personal nature with an association found for both parents' education levels and for the mother's occupational status.

Test (387) examined encouragement given by physics teachers and counselors to students in large public secondary schools to take physics, and their perceptions of reasons for student avoidance of physics. Data were collected using questionnaires that addressed: (a) the exchange of physics course information between students, teachers, and counselors; (b) the method of exchange of physics course information; and (c) the extent to which the physics program is sold to the student body. Also responses were elicited from both physics teachers and counselors that pertained to perceived reasons for students' avoidance of physics courses. Conclusions based on the findings indicated that physics teachers and counselors are not working together to promote physics enrollments; furthermore, there seems to be a negative attitude among school personnel about the probability of increasing physics enrollments in the schools. The data appear to indicate that there is a negative--perhaps even defeatist--attitude among physics teachers regarding physics enrollments. Whatever their reasons (too many course preparations, inadequate physics background, etc.), physics teachers are not committed to increasing enrollment in physics courses.

Smith and Walker (352) compared male and female enrollment and achievement in high school physics courses. A predicted increase from 2:1 male-female ratios found in 1969 was not observed. However, no gender differences were found in achievement.

These findings are disturbing. It appears from these data that teachers are a major cause of low enrollments in physics. Test found that physics teachers and counselors held negative attitudes toward increasing enrollments in that subject. This has a direct influence on maintaining the pattern of low physics enrollments. One can infer that the same condition pertains in chemistry. In addition, the findings of Shepard, Khalili, and Khoury and Voss show indirect influences which teachers have on enrollments: Students' past performance and their attitudes influence enrollment patterns. Results from studies reported in Part A of this section showed that teachers influence students' achievement and, consequently, course selection. Given these findings, teachers, teacher educators, administrators, and policy makers should take initiatives to alter teaching practices and student achievement so that students are prepared both academically and attitudinally for study of advanced science such as physics. Decisive actions are needed so that the science education community ceases to diminish its own effectiveness through continuation of practices which are counter to its own interests and the interests of the society which we serve.

## Studies of Teachers and Teacher Preparation

A large number of studies focused on teachers and teacher education. The following categories were used to organize the review in this area:

A. Studies of Teacher Supply [7]

B. Research on Teacher Attributes [10]

C. Preservice Teacher Education Research [19]

D. Inservice Teacher Education Research. [10]

### Studies Relating to Science Teacher Supply

Shortage of science teachers, now and in the future, is an area of great practical concern. Unfortunately, in the United States, we do not have good data acquisition techniques to help forecast supply of and demand for teachers.

Raizen (309) described data that are available on demand for, and supply of, teachers of mathematics and science. She also pointed out discrepancies and difficulties in current statistics and in collecting the pertinent information. Estimates of supply hinge on identifying who is to be included in the pool of mathematics and science teachers, but there are no commonly accepted measures of competence. Nor is there information on response behavior of potential teachers to various monetary and non-monetary incentives for increasing the supply. Demand estimates are limited by lack of understanding of the impact of increased requirements for high school graduation and college admission. Some suggestions are made for improving future demand/supply estimates.

Walter, et al. (408) studied certification qualifications of biology, chemistry, and physics teachers in Ohio. They found that all teacher preparation institutions in the state are at or above the minimum state requirement in credit hours. Data indicate that low percentages (4-5 percent) of Ohio teachers lack valid certificates for their science teaching assignments.

The current shortage of science and mathematics teachers has engendered many responses including the initiation of incentive programs to attract new teachers and encourage upgrading of existing teachers' skills. Beal et al. (21) conducted a survey of the degree to which incentive programs were being used in 50 states and the District of Columbia to increase the number of people training to be science and mathematics teachers and/or to encourage practicing teachers to upgrade their preparation. A 100 percent return rate was achieved. Responses from the questionnaires indicate that over 50 percent of the states and the District of Columbia have some form of incentive programs as a response to the national shortage of science and math teachers. The most common form of incentive is a loan program with a forgiveness clause. The most common requirement for eligibility is preservice teacher preparation for mathematics and/or science teaching. Some states indicated that they would have had programs but lack of legislative funding prevented this. Appendices include: (1) survey form, (2) listing of types of incentive programs, (3) funding allocation figures, and (4) discipline shortages of states with incentive programs.

Woerner (422) conducted a Delphi study to identify alternatives to attract and retain qualified mathematics and science teachers in Kansas. Five panels of participants were selected from the Kansas Legislature and from the leaders of professional educational organizations representing science teachers, mathematics teachers, other teachers and administra-tors. The major findings of this study showed a high level of agreement among teachers, but there were differences between teachers and administrators and between teachers and the combined group of administrators and legislators.

McManus (251) surveyed over 900 college seniors regarding their perceptions of public school teaching as a career. Education majors and majors pursuing the Bachelor of Science degree were compared on: (a) expected first-year income, (b) ratings given to the importance of selected career factors in choices of careers, and (c) ratings given to the attractiveness of the selected factors in public school teaching careers. Data were collected using the Career Perceptions Questionnaire which was designed for this study. The groups were found to differ significantly in the means of expected first-year incomes. The groups also differed significantly in the means of ratings of importance given to salary, job market, contribution to society, prestige, advancement opportunities, and congenial co-workers. There was no significant difference between means of ratings of importance given to fringe benefits, security, working conditions, and interesting work. A significant difference was found between the means of the two groups on attractiveness ratings given to all career factors in public school teaching except contribution to society.

Crow and Barufaldi (98) described a study of an innovative program for "retooling" elementary teachers in science as vehicle for providing relief for the shortage of science teachers. Data also are presented to depict teachers' concerns, anxieties, and attitudes.

Clark (82) explored the status of science and mathematics at historically black colleges and universities. Results of a questionnaire completed by officials at 47 black colleges show a small increase in percentage of blacks receiving bachelor's degrees in the sciences and mathematics and a small decline in most fields in the award of master's and doctoral degrees. Few of these students are preparing for careers in teaching, which raises serious questions about availability of role models in schools for young black students.

Data on science teacher supply and demand are incomplete, as indicated by Riazen's work. The study by Walter et al. adds some insights about the status of the supply of teachers. It is heartening to know that only 4 - 5 percent of science teachers in Ohio are uncertified. However, data are needed from other states as considerable variations may exist from one state to the next and even within states when one compares urban, suburban, and rural areas. The National Center for Educational Statistics may be able to provide helpful data for those interested in further exploration of this topic.

McManus' study on college seniors' perceptions of teaching as a career, and Woerner's findings regarding differences among teachers, administrators, and legislators regarding opinions about needed actions to alleviate teacher shortages deserve careful examination and interpretation. Crow and Barufaldi's findings on teachers' concerns, anxieties, and attitudes provide an added level of understanding when combined with the results of the two other studies.

What can be said about the incomplete picture which these data show? Of course, more data are needed. We need specific data that will give better quantitative understanding of teacher supply and demand. However, we also need to know more about (a) what attracts people to science teaching, (b) what drives them away, and (c) how teacher education and educational policies can be altered so that better teachers are attracted and retained. A thoughtfully designed plan of research is needed. Such a plan should be welcomed by appropriate funding agencies.

## Research on Teachers' Attributes

Pratt (304) compared teachers' verbal behavior in classrooms and their perceptions of responsibility for success and/or failure of their students. Subjects included 20 experienced science teachers and 22 experienced mathematics teachers from junior and senior high schools in Florida. Data were acquired using the Reciprocal Category System while observing teachers in classrooms. All participants also completed the Responsibility for Student Achievement Questionnaire. Beliefs regarding teachers' responsibility for success or failure of their students differed between those who taught advanced and basic students with the latter assuming greater responsibility for students' success and less responsibility for their failure. Also it was noted that verbal behavior of male and female teachers differed.

Sunal and Sunal (370) studied the relationship of prospective elementary teachers' cognitive functioning and their teaching behavior. Formal thinking abilities were assessed using: (a) traditional Piagetian tasks, and (b) a measure of recognition of formal thought approaches in solving educational tasks. Teaching behaviors were appraised using observational ratings of classroom and planning activities. Subjects assessed as formal operational (30 percent of sample of 91 prospective teachers), had significantly higher facility in performing desired teaching tasks than did subjects assessed as transitional or concrete operational. Higher recognition ability of formal thought approaches in solving educational tasks was not related to classroom performance. Results supported a general portrait of teaching behavior related to teachers of differing cognitive levels.

Oyeneyin (290) studied observing (attentiveness) behavior of undergraduate science education students in Japan. Thirty-two freshmen and sophomores were observed to determine their attentive behavior on four cognitive variables. It was found that 44 percent of students used the fastest mode of short stimulation-short response time. Students using this mode had the lowest mean score on the four cognitive variables.

Boram and Renner (51) conducted interview tasks with 49 prospective elementary teachers enrolled in a physics course, to determine the relationship between their formal thought structures and their success in solving problems related to six physics concepts. Results suggest that, overall, formal thought structure is an important feature in successful problem solutions in physics when such problems require formal thought.

Boehlke (48) conducted an exploratory study to search for possible relationships between science teachers' observed classroom behaviors and their cognitive preferences as measured by the Science Cognition Preference Inventory. Following observations, three groups of teachers were formed: one highest in questioning, one lowest in questioning, and one with indistinct cognitive preferences. Major conclusions were: (1) The three groups of teachers classified on the basis of their cognitive preference tests were found to exhibit different teaching styles. (2) Correlations between particular behaviors increased when data from teachers with only distinct preference scores were used indicating that teachers with distinct preference scores may also have more distinct teaching styles. (3) The results of anecdotal records lent support to the cognitive preference construct. (4) The results of intercorrelations, factor analysis, and score patterns indicated a lack of discrimination between the recall and principle preferences. This lack of discrimination may call into question the traditional definitions of the modes.

Atwood and Oldham (11) studied 146 elementary teachers' perceptions of the effects of mainstreaming students in an inquiry-based elementary science program. Teachers were surveyed for their views on teaching handicapped students in regular science programs. Results showed that teachers in the survey felt positively about teaching handicapped students but many felt inadequately prepared to do so, in spite of inservice training activities.

Robertson (320) surveyed science teachers and school administrators in Mississippi to determine attitudes toward addition of radiation science to the secondary school curricula. A semantic differential test served as the data source. There was strong support for addition of radiation science to the curriculum from all three groups. However, science teachers, principals, and superintendents differed substantially in the amount of information which they had read on the subject.

Hassan (163) conducted a survey of 200 Egyptian Science Teachers and 120 social science teachers regarding their perceptions of the current status and future needs in environmental education in their country. Results showed that school curricula were perceived as moderately effective in developing students' knowledge and awareness of environmental issues and problems. However, teachers perceived school programs as ineffective in developing positive attitudes in students and in fostering skills students will need to solve environmental problems.

Harty and Salama (1[illegible]) studied Egyptian middle school science teachers' attitudes toward lecture methods, their self-concept, and locus of control. The two groups studied were teachers with and without professional educational training. Results showed a set of more desirable attitudes toward lectures, higher self-concept, and greater internal locus of control were found in the group with professional training.

Westerback, Gonzalez, and Primavera (417) studied 58 preservice elementary teachers and 51 geology students regarding ability to identify rocks and minerals and their anxiety associated with the task during an instruction which trained students to observe desired characteristics for grouping rocks and minerals. Results showed that preservice teachers had high anxiety regarding the task which was reduced by task completion. Geology students had lower anxiety, generally, and anxiety and performance were inversely related.

Studies by Sunal and Sunal and by Boram and Renner point up a matter that seems all too obvious: Teachers whose mental functioning is at the formal operational level will be more effective learners of subject matter and pedagogical strategies than those at transitional or concrete operational levels. Moreover, it would also appear that, in the school classrooms, teachers who are functioning at the formal operational level will be able to process information from students more effectively and develop more effective response strategies than those who do not have these cognitive skills readily at their disposal. What should cause worry on the part of teacher educators and policy makers is that 70 percent of the prospective teachers in Sunal and Sunal's sample did not demonstrate capability of formal operational thought. If their finding typifies students in preparation to be teachers, it raises serious questions about the need for entry criteria and/or supplemental cognitive skill training for prospective teachers. Added to this, Oyeneyin's finding that 44 percent of prospective teachers used the shortest stimulation/response modes in making observations suggests specific training needs.

Pratt's study points up an interesting finding about teachers' perceptions of responsibility for success or failure of students. Teachers in basic courses took more responsibility for students' learning than did teachers in advanced courses, reflecting a difference in role perception between the two groups of teachers. It is appropriate to ask, "Is this difference desirable?" Also, what impact does this difference have on students' achievement and on enrollment in elective science courses? Answers to these questions have important implications.

## Preservice Teacher Education Research

Twenty studies focused on preservice teacher education research. These include one demographic study of teacher education faculty and facilities, a meta-analysis of teacher education practices focusing on inquiry skill development, a survey of practicing teachers' perceptions of preservice education needs, and several studies focusing on development of science teaching skills and attitudes.

Barrow (19, 20) conducted a three-part survey of preservice elementary science education in New England. Three reports of the survey provide information about the character of programs at New England teacher education institutions, library resources available throughout the region, and the nature and responsibilities of tertiary level faculty members specializing in elementary science education. Results showed that 15 percent of the institutions do not require elementary education majors to enroll in a science content course and that library resources for preservice elementary science education were judged inadequate.

Sweitzer (372) conducted a meta-analysis of research on preservice and inservice science teacher education practices designed to produce outcomes associated with inquiry strategy. The major problem addressed was the determination of the relationship between methods used to educate preservice and inservice science teachers and the effectiveness of that education in producing intended outcomes associated with inquiry teaching behaviors. Meta-analytic techniques were used to integrate the research between 1965 and 1980. Relevant variables were identified and coded in the following areas: study form and design characteristics, teacher/teacher trainee characteristics, student characteristics, treatment characteristics, outcome characteristics, and effect size calculation characteristics. Sixty-eight studies were coded resulting in 177 effect size calculations. Results showed that clearly focused studies, those using pre-test/post-test design, studies with more dependent variables, and those using specially designed instruments resulted in larger effect sizes. Further, it was found that educational practices exist which were effective in producing their intended outcomes.

Stronck (366) conducted a survey of 1322 elementary teachers and 309 junior and secondary science teachers in British Columbia to determine their perceptions of needed revisions in teacher education programs. A majority of the respondents felt inadequately prepared by their preservice teacher education programs with more than one-third describing their preparation as "very inadequate." Survey results indicated strong support for emphasis on practical aspects of preservice teacher education. Practice in science teaching, techniques of science teaching, and lesson planning were rated highest. Laboratory safety, reading, and writing should receive more attention, according to the respondents.

In studying the influence of a preservice science teacher education program on teachers' perceptions of learning and knowledge, Markovitz and Johnson (245) analyzed data collected over a five-year period. Data were generated from a questionnaire exploring teachers' assumptions about motivation, conditions of learning, social learning, intellectual development, evaluation, and knowledge. Results showed no significant differences between elementary education graduates and undergraduate students, but significant differences were found between undergraduate students majoring in elementary and secondary science education on three scales: assumptions about motivation, conditions of learning, and knowledge requirement of school children.

Tobin (393) examined the influence of strategy analysis techniques in enabling prospective middle school science teachers to implement science lesson segments in a manner that was consistent with strategies incorporated into science teaching models. Conformity to the model was uniformly high for phases related to preparing the learner, investigation planning, and data processing.

Russell (328) and Ponzio and Russell (300) reported on applications of teacher effectiveness research in elementary school classrooms to preservice education of secondary science teachers. The project suggested that skill development in assessing student learning was needed and that training in measurement of academic learning time and active teaching behaviors with student and cooperating teachers would help. All participants reported changes in their teaching as a result of the project ideas and the associated feedback that they received about their teaching. The project was also noted to offer collaboration opportunities between teachers and research project personnel.

El Agha (116) compared the effect of a Personalized Approach and the Traditional Method of instruction in a program for prospective secondary science teachers. Three components of teaching were assessed as dependent variables: unit development, lesson planning, and perception of effective teaching. Two new instruments were developed as criterion measures. Forty prospective teachers in Kuwait were randomly divided into two groups and taught by the same instructor using either the Personalized approach or the Traditional Method for a period of six weeks. Following treatment, tests were given. Analysis of results showed that there were no significant differences between experimental and control groups in unit development and lesson planning, but there was a significant difference in perception of effective teaching, favoring the experimental group. The author concluded that both the Traditional Method of teaching and the Personalized Approach can be used to provide effective instruction for prospective science teachers to develop units, to plan lessons, and to perceive the effective teaching; nevertheless, the Personalized Approach is preferable for instructing the student teachers in Kuwait for perception of effective teaching.

Haury (166) compared the effects of two instructional treatments on prospective elementary teachers' science locus of control orientation. Both treatments were known to have positive effects on attitudes, but the experimental treatment was novel in its emphasis on self-management, goal clarification, and individualized course expectations. Although the treatment effect is small, accounting for three percent of the variance, science locus of control orientation was shown to be susceptible to educational intervention.

Wesley et al. (416) examined the effects of computer-assisted instruction on 81 preservice elementary teachers' acquisition of integrated process skills. Results demonstrated that a text mode of programmed instruction and tutorial computer-assisted instruction are equally effective modes of instruction for teaching both internally-and externally-oriented preservice elementary teachers the integrated science process skills.

McKenzie and Karnau (250) studied the effects of a computer-based diagnostic test on laboratory achievement in general science, using a group of 91 preservice elementary teachers. Prospective teachers who experienced the diagnostic test as part of their instruction did not score significantly better than peers in the control group on a laboratory examination, although students perceived the diagnostic test to be helpful.

Psillos et al. (307) investigated preservice physics teachers' ability to make judgments of observed teaching during one of two courses. Students in an inductive course engaged in peer teaching before receiving instruction in theory. Students in a deductive course received instruction in theory before peer teaching. The first part of each course, irrespective of its content, resulted in changes of students' evaluation of teaching. Students' knowledge of pedagogical theory was found to be related to their judgments of observed teaching and the quality of their own teaching.

Butler (64) studied the patterns of journal reading of senior science education students at the University of Oklahoma during the period from 1972-1983. Data on journal popularity among students and reading patterns within subject areas are reported.

A study by Martin (248) provided general support for application of the credibility principle in changing attitudes of prospective elementary teachers. Following a 10-week methods course, which involved both school- and university-based components, students' attitudes toward science and science teaching showed general improvement and there were no changes in their ranking of the credibility of professional staff.

Lawrenz and Cohen (224) examined elementary and secondary teacher education students' attitudes and understanding of science processes prior to taking methods courses, immediately after completing the courses, and upon completing their practice teaching experience. Elementary education majors from one university and secondary education majors from another university were included in the study. The Science Attitude Inventory and the Science Process Inventory both were administered prior to the methods course, between the methods course and practice teaching, and after practice teaching. Results obtained after the methods course showed more positive attitudes toward science of both elementary and secondary students. However, after practice teaching, scores on the Science Attitude Inventory showed a significant decline for secondary majors and no significant change for prospective elementary teachers. No significant changes were noted for any comparisons of Science Process Inventory scores.

In studying the responses of 79 prospective elementary science teachers enrolled in a science methods course, Koballa (213) presented persuasive communications about energy conservation and then tested for their retention of arguments and their cognitive responses. Attitude change was found to be significantly correlated with cognitive responses both immediately following treatment and three weeks later. No significant correlation was found between recall of arguments and attitude change.

Zeitoun and Hassan (430) examined the effect of written persuasive biology communication on attitudes toward teaching organic evolution of prospective biology teachers in Egypt. A 22-item Attitude Toward Teaching Evolution Scale was developed for the study along with persuasive written communication for both experimental and control groups. Treatment and criterion measures both consisted of opposing arguments for teaching organic evolution. Results indicated that written persuasive communication had a positive influence on treatment of group members attitudes toward teaching organic evolution in secondary schools.

Nabors (264) studied the effects of persuasive communication on changing attitudes of 88 female preservice elementary teachers toward viewing science an an enterprise for both sexes. Using a pretest/posttest experimental design with treatment and control groups, the dependent variables were: (1) the females' attitude changes in viewing science as an enterprise for both sexes, as measured by the Attitude Toward Science as an Enterprise for Both Sexes Scale; and (2) the persistence of attitude change. The independent variable was the persuasive communication. The results indicated that the subjects from both groups obtained high attitude scores toward viewing science as an enterprise for both sexes. The study concluded that, contrary to findings reported in the literature, females do feel that science is an enterprise in which men and women can achieve on an equal basis.

Hassan and Shrigley (164) studied the effects of written, persuasive communication on the attitudes and self-esteem of preservice teachers. Results indicated written persuasive communication could change the attitudes of the preservice elementary teachers in this study. No significant differences in self-esteem were found as a result of this treatment.

Due to overlap among studies in the two sections, interpretation of results of these studies of preservice education is included with the interpretation of the next section.

## Inservice Teacher Education Research

Ten reports of research on inservice teacher education were reviewed. Four of these were classified as needs assessments, two emphasized subject matter knowledge, and four emphasized acquisition of pedagogical knowledge.

**Nash** (268) conducted a study to develop a graphic model of a teacher center that would serve middle and high school science teachers and to: (a) determine the characteristics of such a teacher center, (b) compare the graphic model so developed to professionals' perceptions of what such a teacher center should be, and (c) compare a selected sample of established teacher centers with the proposed model. A non-random sample of science teachers and other professionals was surveyed to determine: (a) the extent that the graphic model fit their perceptions of what a science teacher center should be, and (b) the characteristics such a center should have. Five teacher center directors were interviewed to determine the extent to which the proposed model agreed with their perceptions. Also, prepared descriptions of each teacher center were compared with the proposed model. The model included science teachers' concerns as a central focus, surrounded by teacher educators' concerns, with the outer "shell" of the model addressing societal concerns. The following conclusions were drawn: (a) A teacher center designed to meet the needs of science teachers should focus on the teaching-related concerns of science teachers. (b) Middle and high school science teachers and professional inservice educators' perceptions of a teacher center compared favorably with the proposed graphic model. (c) The teacher centers studied were not of the comprehensive level favored in the model.

**Spector** (356) used qualitative research methods to assess training needs of science teachers in southern Florida. Data were acquired from individuals and groups within and outside of the educational enterprise, including those who can influence educational policies and their implementation. The study resulted in recommendations for graduate education and non-credit inservice activities for science teachers, based on a task analysis of science teaching in the 1980's and beyond.

**Zurub and Rubba** (432) reported on a study of inservice teacher education needs of Jordanian secondary science teachers. They appraised differences in needs among various specialty areas. It was found that the most prevalent needs were associated with science instruction delivery, facility and equipment administration, and improvement of competence levels as a science teacher.

**Jbeily and Barufaldi** (192) studied Lebanese secondary science teachers' perceptions of needs and concerns using a modified version of the Moore Assessment Profile and the Teacher Concerns Statement. Results indicated that physics, chemistry, and biology teachers, respectively, shared 6, 9, and 21 high priority needs including concerns relating to tasks and impact of instruction.

Arnold (9) conducted a study to determine whether the Physics Resources and Instructional Strategies for Motivating Students (PRISMS) program influenced the teachers' knowledge of physics. Data were collected through pre- and post-questionnaires administered to 29 teachers and administrators. Pre- and post-assessment instruments were developed to measure the teachers' knowledge of physics content. The data indicated that the teachers' attitudes toward teaching physics and the PRISMS program decreased from a positive attitude to a less positive attitude. The teachers' knowledge of physics increased as a result of PRISMS, and the teachers became more comfortable with presenting physics concepts. The teachers' level of knowledge was influenced by years in teaching physics, and by the number of semester hours taken in college physics. Finally, the teachers' and administrators' opinions on selected statements decreased from a more positive opinion to a somewhat negative opinion. The interesting question for further investigation pertains to the causes for the decreases in teachers' attitudes and opinions and the impact of PRISMS on students' learning and attitudes.

Kirman and Goldberg (212) used one-way television and group-telephone conferencing as a vehicle for training 30 Alberta (Canada) elementary teachers in the use of area LANDSAT imaging with their classes. Results showed that both teachers and elementary students were able to interpret LANDSAT imaging, but some difficulties were noted.

Davivongse (101) conducted a study to assess the effectiveness of a training program designed to assist Thai junior high school science teachers in asking a larger number of higher cognitive level questions, extending wait-time following a question, and decreasing the amount of teacher talk during classroom instruction. Sixty-two teachers were randomly assigned to treatment and control groups. Teachers in the treatment group were given training on questioning techniques, wait-time, and to analyze their own questions and wait-time behavior. Tape recorded lessons were supplied by each teacher before and after treatment. Findings showed that the training program was effective in training teachers to decrease the number of cognitive-memory questions and increase the number of divergent thinking and evaluative thinking questions they asked, extending teacher wait-time, and reducing the amount of teacher talk during instruction in the science class. No significant change occurred in the number of convergent thinking questions or the total number of all cognitive-level questions asked by the teachers.

Lombard et al. (235) implemented and evaluated an inservice program to promote student reasoning using the learning cycle. The report is comprised of: (a) a description of the program, and (b) a report of their evaluation of its effects on teachers. Findings emphasized the importance of collaboration between colleagues and the utility of peer coaching in initiating and maintaining an innovation.

Heard and Marek (170) presented a progress report on a study of relationships between an inquiry-oriented science inservice education program and teacher implementation of workshop-developed materials. A pretest-posttest design was used to measure the effects of the workshop on teaching methodology and on the knowledge organization and cognitive performance level of their students. Comparisons between the groups were made, noting the intellectual developmental levels and the language used when describing the objects. Since this research involved a thorough analysis of both the classroom and student interviews, an anthropological approach was used (with posttest data being collected during May, 1985). Two findings from pretest data were: intellectual development of experimental and control group members was approximately the same and experimental group members could utilize property words better than could control group members.

Donaldson (107) conducted a study to determine the extent of agreement between selected elementary science educators and selected fourth, fifth, and sixth grade science teachers in Kansas regarding science laboratory teaching competencies that should be possessed by these elementary teachers. The subjects were 107 college educators across the nation and 256 elementary teachers from various school districts in Kansas. A survey instrument was used to acquire demographic data and data on operational, process, management, developmental, and evaluation competencies. Of the twenty-one items identified in the category of operational competencies, nine yielded significant distributional differences. Science teachers believe there is a somewhat greater need for the three competencies of use of the microscope, cleaning glassware, and use of models. Science educators perceive a somewhat greater need for comprehension of cultures in the classroom, use of taxonomic keys in identification, use of terraria and aquaria, use of the metric system, use of histograms, and use of electric circuits. There were no significant distribution differences between the two groups in twelve of the items. All six items within the process competencies yielded significant distribution differences. Teacher educators regarded all six process competencies at a higher need level than did science teachers. The four items within the management competencies did not yield significant differences between the two groups. Of the four items within the area of developmental competencies, hands-on approaches, individualized learning, and low-budget or homemade materials were favored more by teacher educators than by teachers. Of the seven items within the category of evaluation competencies, three yielded significant distribution differences, with teacher educators favoring skill tests and checklists, student feedback instruments, and audio-tape techniques.

In examining the 29 studies in these two sections on preservice and inservice teacher education research, I was struck by the fact that only about seven percent of the research in science education during 1985 addressed teacher education. This was surprising, since nearly all of those engaged in science education research are also engaged in teacher education. Further, much of this research focused on education of elementary teachers, for whom science is only a small part of their work. As a consequence, less than three percent of our research focused on education of secondary science teachers. This number is further diminished by the fact that several studies of secondary science teacher education were conducted outside the United States. Thus, very little research is being carried on regarding education of secondary teachers in U.S. universities. Much more work is needed on this important area.

The findings of research in these two sections provide important information. Studies by Stronk, Markewitz and Johnson, and Donaldson, show us that teachers desire different and better preparation than they are receiving. Moreover, Donaldson's study points up significant differences in values and beliefs of science teachers and science teacher educators. These data deserve careful analysis by science educators since it appears that they should give increased attention to the practice of science teaching in the schools.

The work of Davivongse, Kirman and Goldberg, Psillos et al., Tobin, Russell, and El Agha all show that specific training resulted in desired outcomes. However, Arnold and Lawrenz and Cohen found that training was followed by a decline in teachers' attitudes. On the other hand, Lombard found that inservice training that involved collaboration of teachers and peer coaching was effective in maintaining innovation. These findings point up a need for comprehensive research which examines the overall impact of programs in participants' knowledge, attitudes, skills, and their propensity to apply their new knowledge in their practice of teaching.

Finally, a study by Butler on journal reading highlights a needed area of research. We know very little about how science teachers keep current in their knowledge about science, pedagogy, and new developments in science teaching. My own research suggests that many secondary science teachers acquire new information at a very slow rate and in an unsystematic manner. More study in this area is needed as it has important implications for both inservice and preservice science teacher education.

## Epilogue

Reviewing, summarizing, and interpreting research is an important activity for all members of the science education community. Most of us probably do not do enough of it beacuse it is a time consuming task, and we are confronted with other demands and deadlines which are not as easily put aside as this one. Reviews such as this Annual Summary of Science Education Research, and other critical analyses that are published, are important to all of us because the investment of time in this intellectually demanding and tedious work by a few people benefits many.

The task of reviewing research could be lightened, at least in a small way, if authors would write better abstracts when reporting their studies. A clear statement which describes purposes, methods, instrumentation, population, results, conclusions and implications, presented in a standard format, limited to approximately 150 words, should be required of all who publish papers. These should be given careful attention by writers because of their potential utility in helping others in the field gain rapid access to research findings.

Those of us who are engaged in the education of new researchers in advanced graduate programs in science education should give careful attention to the writing of abstracts as an important skill in analyzing and interpreting research of others and also as a necessary skill for reporting of research.

As stated in the introductory section of this Research Summary, there is a need for sharply focused critical analyses of specific research topics in science education. Each new research activitiy should begin with a critical anlaysis of pertinent research. Critical reviews of relevant literature are a standard part of dissertations, but usually they are not published, and thus are accessible only to those who obtain a copy or microfilm of the dissertation. While accessing dissertations is relatively easy, the field of science education would be enriched if more attention were given to publication of top quality critical reviews from dissertations. Moreover, all members of the science education community should give greater attention to preparing and publishing critical analyses of research in their respective fields as a way of building and consolidating our cumulative knowledge base in the field.

In closing, I hope this Annual Summary will be stimulating and useful to those who read it. It has been a challenge and an accomplishment to prepare it for you. To those who will prepare subsequent Annual Summaries, I hope the pattern I have used it this report may be helpful.

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